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ON ESTIMATING THE COST GROWTH OF WEAPON SYSTEMS

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June 1980
(Revised September 1984)

INSTITUTE FOR DEFENSE ANALYSES
COST ANALYSIS GROUP

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This paper documents schedule and cost growth in major DoD weapon system acquisition programs that have attained Initial Operational Capability (IOC). Utilizing Selected Acquisition Report data, a methodology for projecting probable future growth in evolving systems that have not yet reached IOC was developed and described. Use of the growth projection methodology as an adjunct to future IDA weapon system analyses is recommended.

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PREFACE

Schedule and cost growth in DoD weapon system acquisition programs have been recognized as an economic fact of life. This growth has been the subject of many studies and analyses that have documented the phenomenon. A variety of causal factors have been identified, including:

- General economic inflation
- Supply/labor shortages
- Technological uncertainty
- Specification changes
- Changes in threat
- Budgetary constraints

While it may be interesting and informative to know why growth has occurred, senior decision makers need a realistic and simple-to-use method whereby they can project the probable cost of a system by the time it has matured enough to be placed in the hands of a using unit (i.e., by the time the system attains its initial operational capability).

This paper briefly outlines the weapon system acquisition cycle and the associated DoD management processes and tools. Its purpose is to develop a methodology for projecting future growth in individual programs. To this end, a total of fifty-two major weapon system programs were examined for schedule and cost growth. The primary data source used in this effort was the Selected Acquisition Report--the official report used by the DoD to provide the Congress with updated cost, schedule, and performance data on new major acquisition programs.

Acquisition programs were split into four categories: aircraft, missiles, ships, and other systems. Within each category, individual weapon system schedule and cost growth was documented. Median and mean factors were derived for schedule, development cost and procurement unit cost growth. A schedule and cost growth projection methodology that relies on a simple charting technique was developed and then explained in a series of sketches and examples.

ABSTRACT

This paper documents schedule and cost growth in current major DoD weapon system acquisition programs that have attained Initial Operational Capability (IOC). Utilizing Selected Acquisition Report data, a methodology for projecting probable future growth in evolving systems that have not yet reached IOC was developed and described. Use of the growth projection methodology as an adjunct to future IDA weapon system analyses is recommended.

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ABBREVIATIONS

CE	Current Estimate
DAE	Defense Acquisition Executive
DE	Development Estimate
DCP	Decision Coordinating Paper (formerly Development Concept Paper)
DSARC	Defense Systems Acquisition Review Council
DTC	Design-to-Cost
FYDP	Five-Year Defense Program
HARM	High-Speed Anti-Radiation Missile
IOC	Initial Operational Capability
IPS	Integrated Program Summary
JMSNS	Justification for Major System New Start
LCCE	Life-Cycle Cost Estimate
MAA	Mission Area Analyses
MENS	Mission Element Need Statements
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
PdE	Production Estimate
PDM	Program Decision Memorandum
PE	Planning Estimate
POM	Program Objective Memorandum
PPBS	Planning, Programming and Budgeting System
PUC	Procurement Unit Cost
RDT&E	Research Development Test & Evaluation
RFP	Request for Proposal
SAR	Selected Acquisition Report
SCP	System Concept Paper

(S)SARC	(Service) Systems Acquisition Review Council
SDDM	Secretary of Defense Decision Memorandum
SECDEF	Secretary of Defense
SOR	Stated Operational Requirement
SRAM	Short-Range Attack Missile

I. INTRODUCTION

The actual costs of weapon systems are almost always greater than estimates made during their planning and development phases. Accordingly, in studies involving the cost-effectiveness of weapon systems, current cost estimates of systems not yet deployed should be adjusted to reflect probable future cost growth. This adjustment is particularly important in studies involving the relative costs and effectiveness of weapon systems at different stages of their life cycle. Use of unadjusted costs would tend to favor unfairly those systems in earlier stages of development relative to those systems in later stages of development or deployment. This paper presents a methodology for making such adjustments to current estimates.

The IDA schedule and cost growth projection methodology uses the Selected Acquisition Report (SAR) as its data source. The SAR was chosen because it is an official report submitted by the Office of the Secretary of Defense (OSD) to the Congress on the status of major acquisition programs. The SAR is a highly aggregated report which is focused on the "bottom-line" roll-up of a program's estimated acquisition costs. It is the one DoD document most often cited in Congressional and GAO reports dealing with cost growth.

This paper treats cost growth in weapon system acquisition programs as an economic fact of life. It does not address operating and support costs of a system once the system is fielded (deployed). The basic purpose of the paper is to provide a mechanism whereby the potential for cost growth in a

program can be illuminated and quantified. The methodology is not a vehicle for explaining why growth occurred. The approach is straightforward and treats all programs on an "other things being equal" basis. As is the case with any estimating technique, the IDA growth projection methodology is not a panacea. Its use is most appropriate where data, existing cost estimating relationships, time or resources are not adequate or available to complete an independent cost analysis of a given program.

This study was performed under the IDA Independent Research program. Use of the proposed methodology in future weapon system studies and analyses is planned. This revision is the second update of this paper. Additional updates are anticipated when other major systems currently under development attain IOC.

II. PAST STUDIES OF COST GROWTH

A literature search provides many references to cost growth, a few of which are presented below.

A 1978 GAO Report (Ref.1) opened with the following:

> On March 27, 1794, the Congress authorized the building of six large frigates which were to form the backbone of the U.S. Navy. The then War Department was assigned the task of acquiring the ships. Nearly 17 months later the six keels were laid. Shortly thereafter, due to delays and cost overruns, the program was cut back to three frigates.
>
> Today, 184 years later, most Federal agencies are faced with the same problem--ultimate costs of major programs are often many times the estimated costs on which they were approved.

A 1965 Anser Memorandum (Ref.2) reported:

> The incongruity between estimated and actual costs of today's weapon systems indicates a need for cost estimates which more accurately predict the cost of future weapon systems. Estimates made near the beginning of a development program are particularly unreliable. For example, the cost of developing 11 existing weapon systems was as much as seven times the amount originally estimated. A study of the development and production costs of 33 weapon systems showed that the original cost estimates were 180 to 220 percent too low, on the average, even after price-level and cost-quantity adjustments were made.

A 1972 Rand Paper by Alvin J. Harman (Ref.3) indicated a continuation of cost growth:

> Improvement in the process of acquiring major weapon systems has been the subject of analyses and policy recommendations for several decades [see, for

example, Klein (1962)[1], Peck and Scherer (1962)[1], Marschak, et al. (1967)[1], Perry, et al. (1971)][1]. While system costs have increased as weapon systems have grown more complex, for programs of comparable duration and technical difficulty, the extent of cost growth over original estimates has not significantly improved [Harman (1970)][1].

A 1965 Rand Memorandum (Ref.4) noted that cost growth is also widely experienced in major civil projects.

Twenty-two chronologies of cost estimates of major articles of Air Force weapon systems constitute the basic data of this study. Even a cursory examination of the chronologies suggests that the estimates leave much to be desired. It should be recognized, however, that predicting how much something will cost that is to be produced a long time in the future is always a hazardous activity. The United States is studded with railroads, canals, tunnels, bridges, and highways that cost a great deal more than was originally expected. For example, the final cost of the Troy and Greenfield Railroad was more than ten times as much as the original estimate, principally because tunneling four miles through Hoosac Mountain turned out to be enormously more difficult than the railroad's geologists had predicted. The Welland Canal cost many times more than was expected because the height of a major cut, estimated at 30 feet, was actually 60 feet.

The Suez and Panama Canals tell much the same story. The earliest cost estimate for the Suez Canal, a half-century before it was finally built, was low by a factor of twenty; the year before digging actually began, the estimate was still low by a factor of three. The early abortive effort by the French to build a canal across the Isthmus of Panama was undertaken as a result of a substantial underestimate of the magnitude of the task. The total outlay on the project by the French and subsequently the United States was about twice what the French originally thought would be necessary. Even though the United States had the French experience to learn from, and a portion of the job was already done, the American outlay was 70 percent more than anticipated when the American work began.

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[1] See Harman reference list, p. 76.

The nuclear power plants recently built offer another example. Almost without exception, the initial cost estimates for these plants were too low. Costs climbed from 50 percent to 100 percent, and in some cases are still climbing. It is instructive to examine the breakdown given by Consolidated Edison for the cost increases they experienced in their Indian Point plant. Though the total cost went up about 90 percent, expenditures on the strictly nuclear portion of the plant went up by a factor of three; the increase for the conventional elements, on the other hand, was only 37 percent. If one allows for general price-level increases and a slight change in gross capacity, the increase for the nuclear part of the plant still amounts to a factor of about two-and-a-half.

A 1972 Ph.D dissertation (Ref.5) included a review of the literature on cost growth of weapon systems.

The most sophisticated studies of actual cost performance on programs as compared to original cost estimates were the Merton J. Peck and Frederic M. Scherer studies[1] and several Rand Corporation studies.

Peck and Scherer analyzed twelve typical weapon systems programs of the 1950's. All twelve systems employed cost-plus-fixed-fee contracts. The average cost growth was found to be 220 percent beyond original target cost.[2]

Almost identical results came from a later study of 22 Air Force weapon systems programs involving 68 estimates. The study, entitled Strategy for R&D: Studies in the Microeconomics of Development, by Thomas Marschak, Thomas K. Glennan, Jr., and Robert Summers of Rand Corporation, showed an average cost growth of 226 percent beyond original estimated cost.[3] These programs also entailed primarily cost-plus-fixed-fee contracts of the late 1950's.

In the 1960's, incentive contracts, rather than cost-plus-fixed-fee contracts, were used for most engineering development efforts. One might therefore

[1] Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process--An Economic Analysis* (Boston: Graduate School of Business, Harvard University (1962).

[2] *Ibid.* p. 429.

[3] (New York: Springer-Verlag New York, Inc., 1967), p. 152.

expect actual program costs to be closer to original cost estimates. Two such studies of the 1960's were undertaken by Rand personnel.

Robert Perry et al. reported in a study of 21 Army, Navy and Air Force system acquisition programs that, "...[O]n average, cost estimates for the 1960's were about 25 percent less optimistic than those for programs for the 1950's. Thus, if reduction in bias (or reduced optimism) is a realistic index of "better" there is evidence of improvement in the acquisition process."[1] Even such a statement as this must be hedged considerably as Perry et al. were careful to do. "Still, the model has little explanatory power (in a statistical sense), and it does not indicate *why* improvements have occurred."[2]

In contrast, a more recent Rand follow-up study discounted any improvement in the 1960's over the 1950's noting that, "...[F]or programs comparable in length and difficulty, 1960's procurements would have resulted in actual costs exceeding estimates by roughly the same proportion as had 1950's procurements.[3]

A 1978 paper by Truman W. Howard (Ref.6) summarized the results of some other studies dealing with growth:

Cost histories of 45 systems under development in June 1972 showed that estimates one year later exceeded development estimates by 20 percent ($19.1 Billion) [3].[4] Such widely publicized overruns have a severe impact on the credibility of both Government and industry management. One case, the C-5A airplane, nearly doubled its estimated unit cost from $28 to $55 million dollars over a five-year period [3].[4] Such cost growth experience is not new. Peck and Scherer [10][4] analyzed 12 weapon system development programs in the 1950's and found that development costs averaged 3.2 times the

[1] *System Acquisition Experience*, Memorandum RM-6072-PR, prepared for United States Air Force Project Rand (Santa Monica: The Rand Corporation, November 1969), p. 6.

[2] *Ibid.*

[3] Alvin J. Harman, *A Methodology for Cost Factor Comparison and Prediction*, Memorandum RM-6269-ARPA, prepared for Advanced Research Projects Agency (Santa Monica: The Rand Corporation, August 1970), p. 6.

[4] See Harman reference list, p. 76.

original estimate, and schedule slippage averaged 1.36 times the original estimate. Trainor [12][1] in a more recent study, analyzed nine major DoD and NASA development systems. Development costs averaged 1.31 times the original estimate, and schedule slippages averaged 1.6 times the original estimate.

A 1978 GAO Report (Ref.7) indicated pervasive cost growth for both military and civil major acquisitions:

> The estimated costs of major acquisitions have increased each year since June 30, 1975, when we issued our first combined military and civil major acquisitions status report on 585 projects estimated to cost $404 billion at completion. The estimated costs of 857 major acquisitions at September 30, 1978 have increased $49 billion over the past year to more than one-half trillion dollars.

A report of Congressional hearings on DoD cost estimates conducted in 1979 (Ref.8) concluded:

> The hearings focused on the validity and overall value of Department of Defense cost estimates given Congress at two critical stages in weapon systems procurement--(1) at the initial, conceptual stage when a Planning Estimate (PE) is made and Congress has to authorize and appropriate the money for a new weapon system, and (2) at the time full-scale production [sic][2] funds are requested, when a baseline Development Estimate (DE) is given. The Planning Estimate and the Development Estimate were then compared to the Current Estimate (CE) that is reported in the quarterly SAR.
>
> Since 1969 the initial (planning) estimate has turned out to be approximately 100 percent below the actual costs of major systems. The later, more refined development cost estimate given Congress prior to full-scale development has proven to be approximately 50 percent below actual procurement costs.
>
> The review by the Subcommittee failed to find one example where the Department of Defense accurately estimated or overestimated the cost of any major weapon system.

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[1] See Harman reference list, p. 76.

[2] "Production" used incorrectly; should have been "development."

These excerpts reveal a consistent and continuing pattern over many years of cost growth on both military and civil major acquisitions. Additional references are included in the list of references.

Much has also been written on the causes of cost growth. Some of the more frequently cited causes are:

"Force Majeure"

- Natural disaster
- Civil disorder
- Labor strike
- Fire

General Economic Inflation

Cost estimates based on previous similar system (each succeeding generation tends to cost more than last generation).

Supply shortages

Labor shortages

Poor management

Technological uncertainty

- Unknowns
- Unknown unknowns

Environmental laws/regulations

Specification changes

Quantity changes

Reliability problems

Concurrency (trying to produce too fast)

Tight budgets

Competitive environment

- within branch of service
- within service
- among services
- DoD vs. other federal agencies
- Executive branch vs. Congress

- among contractors
- among individuals

While the above list may not be exhaustive, we believe that two causes must be singled out because of their impact. First of all, we believe that the competitive environment in which weapon systems are developed is the major factor leading to cost growth. All weapon systems must compete for funds at many levels within the federal government. This competition involves both implicit and explicit rankings of competing systems on a cost-effectiveness basis. Effectiveness usually involves intangible factors as well as characteristics that can be measured quantitatively. However, cost is only expressed in quantitative terms. There is an obvious incentive for the proponents of a system to underestimate its cost in order to increase its probability of acceptance.

Secondly, tight budgets are an often-overlooked cause of cost growth. There is a management school of thought which holds that overly-generous budgets lead to unnecessary costs. This basic idea was popularized as one of Professor Parkinson's laws (Ref.9).

> Work expands so as to fill the time available for its completion.

In order to avoid this pitfall, tight budgets (and schedules) are established and so contribute to later cost growth. This same idea was discussed in a paper by Wayne Allen (Ref.10).

> As dollars are the most widely used control mechanism, a practice of minimizing estimates of future costs has evolved as a management technique for attempting to impress contractors with the continuing need to produce more for less and in a shorter period of time.

And, in a Rand report (Ref.11):

> The conventional view is that a contractor is more motivated to economize and to attempt to find ways to reduce cost if a development contract is negotiated for the lowest possible amount and if the

> planning estimate for production items is also low. Cost growth may occur, but it is assumed that final cost would have been even higher had the contractor not been constrained by the low early estimates.

Although writers have different opinions of the relative importance of various causes of cost growth, there is general agreement that there are a number of contributing factors, and program results almost invariably exhibit resulting cost growth. Accordingly, in Chapter V we present a method by which cost estimates of weapon systems in development can be adjusted upward in order to predict more accurately their probable future costs regardless of cause.

III. DoD WEAPON SYSTEMS ACQUISITION MANAGEMENT AND THE SELECTED ACQUISITION REPORTS (SARs)

The continued schedule and cost growth experienced in major weapon systems acquisition programs is frequently cited by critics of the Defense establishment as an indicator of poor management practices. While this statement is an over-simplification of an extremely complex problem, given the various reasons for schedule and cost growth enumerated in the previous chapter, it may be helpful to review briefly the process whereby the DoD manages the acquisition of new major weapon systems and the reporting procedures which allow Congress to exercise its responsibilities for oversight. A familiarity with the management process and reporting procedures is a prerequisite to an understanding of the growth projection methodology proposed in Chapter V. Accordingly, the focus of this chapter will be on the Defense Systems Acquisition Review Council (DSARC) process and the Selected Acquisition Reports. The latter are the official means employed by the Department of Defense to provide Congress with updated cost, schedule, and performance data on major weapon systems, while the former (the DSARC process) provides the base for the data contained in the SARs.

A. THE MAJOR SYSTEM ACQUISITION PROCESS

The current major system acquisition process was established in 1968 to provide a means for better managing the acquisition of major systems (a major system is any development effort so designated by the SECDEF. Usually, those programs whose RDT&E costs are projected to exceed $200 million or

procurement costs are projected to exceed $1 billion in FY 80 constant dollars are designated major programs). DoD Directive 5000.1 and DoD Instruction 5000.2[1] govern this process, which is now made up of four phases, through which a program normally proceeds before a system is actually fielded. Decision points (or milestones) mark the entry into each succeeding phase of the process. See Figure 1.

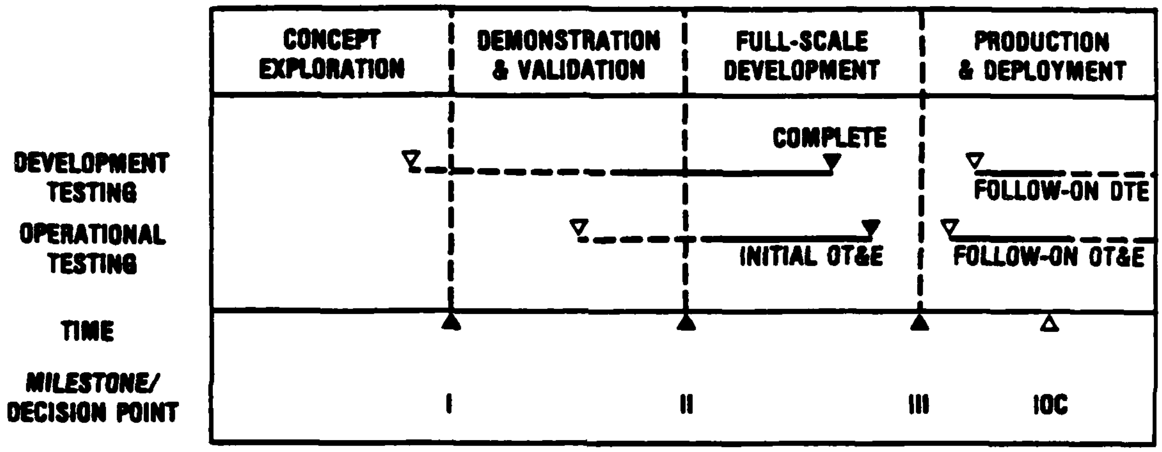


Figure 1. PHASES OF THE ACQUISITION PROCESS

At each key decision point, top management of the sponsoring Service will gather together in a series of meetings culminating in a (Service) Systems Acquisition Review Council (S)SARC meeting to review all aspects of a particular program and its alternatives. Recommendations of the (S)SARC are reviewed and approved by the Service Secretary prior to

[1]DoDD 5000.1, "Major System Acquisitions," March 29, 1982.
DoDI 5000.2, "Major System Acquisition Procedures," March 8, 1983.

forwarding his decision on the program to OSD for review. OSD will then convene a Defense Systems Acquisition Review Council (DSARC) which is chaired by the Defense Acquisition Executive (DAE) who currently is the Under Secretary of Defense for Research and Engineering. The DSARC conducts an independent review of the program and makes its recommendations to the Secretary of Defense. SECDEF approval is announced in a Secretary of Defense Decision Memorandum (SDDM) that signals successful completion of a milestone and is authorization to proceed into the next phase of the acquisition cycle.

The materiel acquisition process complements the DoD requirements definition process. Statements of weapon system requirements result from continuing evaluations of existing technology, threat, doctrine, organizations, and materiel systems (i.e., technical and operational suitability, system assessments, logistic assessments, and readiness reviews). These evaluations are known as mission area analyses (MAA). MAA needs also arise from Program 6.1, "technology base" efforts. MAA deficiencies or needs are cited in Justification for Major System New Start (JMSNS) which are forwarded to the Secretary of Defense for approval as part of the Service's Program Objectives Memorandum (POM) submission.

MISSION NEED--CONCEPT EXPLORATION PHASE

Mission need determination is accomplished in the Planning-Programming-Budgeting System (PPBS) process based on a Component's JMSNS/POM submission. The Secretary of Defense provides appropriate guidance in the Program Decision Memorandum (PDM) which is issued to the Service(s) to explore and develop alternative system concepts to satisfy the approved need. This action provides official sanction for a new program start and authorizes the Military Service, when funds are available, to initiate the first phase of system development. A major part

of this phase is the development of program estimates for each of the conceptual system alternatives deemed feasible. These estimates are not considered firm since systems are not clearly defined and the values for system parameters are uncertain.

MILESTONE I--DEMONSTRATION AND VALIDATION PHASE

The first major decision point is reached at the end of the Concept Exploration Phase. The program life-cycle cost estimates (LCCE) that address the estimated acquisition (development and procurement) and ownership (operating and support) costs of all the alternatives to be considered at this decision point are incorporated into a document called the System Concept Paper (SCP). The SCP provides the primary documentation (acquisition strategy, alternatives, and issues) for use by the DSARC in arriving at its milestone recommendation. One or more system concepts are nominated by the DSARC to proceed through the next phase of the acquisition process. For very select high-interest programs, the acquisition portion of the LCCE is incorporated into a program monitorship report. This report, established in 1968, is called the Selected Acquisition Report (SAR).[1] It serves as the baseline for monitoring future program performance. At this point, the SAR program estimate is referred to as the "planning estimate." The planning estimate is also used in the PPBS to plan for the financing of the program.

During this phase, prototype systems may be developed and tested to prove that hardware can be built to meet the requirement of the conceptual system. The program selected at Milestone I may not call for total development of a new system. The selected program may only involve modifying an existing system to a configuration that meets the required

[1]DoDI 7000.3, "Selected Acquisition Report," March 2, 1983.

need. In such cases, prototype systems are not built. At the end of this phase, an analysis is conducted to prepare for the nex. decision point. This analysis involves reconfirmation or rejustification of the requirement against the latest threat assessment, and the preparation of updated program estimates. These estimates make use of new information acquired during the developmental and testing efforts. These are the first estimates based on information gained from actual development and testing of system hardware.

MILESTONE II--FULL-SCALE DEVELOPMENT PHASE

The second decision point of the acquisition process occurs at the end of the demonstration and validation phase. The program estimates of all the alternatives are recorded in the Decision Coordinating Paper/Integrated Program Summary (DCP/IPS). The DCP/IPS consists of two documents that provide different levels of detail for consideration by the DSARC. The DCP is a top-level summary document that identifies alternatives, goals, thresholds, and threshold ranges, as appropriate. The IPS will provide more specific information on the program and is prepared when the DAE determines that the DCP lacks information on which to base the requisite decision. The estimate of the program alternative selected by the (S)SARC and DSARC becomes the new *baseline* for the program. Management thresholds are established about this new program estimate. These thresholds serve as a means for controlling the program within prescribed levels of allowable changes that may subsequently occur. Concurrently, the acquisition portion of the program estimate is substituted in the SAR for the planning estimate, and becomes the new baseline for monitoring program performance. In the SAR this revised baseline is referred to as the "development estimate." This estimate is also used for programming and budgeting purposes. It must be noted that for

most systems, SAR submissions begin after a Milestone II decision has been made.

Prototype systems are also built during this phase of the program. In the demonstration and validation phase, prototypes were built to demonstrate the ability to build a weapon system possessing the capabilities required to respond to the need. Having proven this capability, the prototypes in full-scale development are built to demonstrate the ability of the system to perform successfully in the field and to demonstrate the adequacy of the system's design for eventual quantity production. Upon completion of this phase, another analysis is conducted in preparation for the final program decision. This analysis again involves reconfirmation or rejustification of the requirement against the latest threat assessment and the preparation of updated program estimates.

MILESTONE III--PRODUCTION AND DEPLOYMENT PHASE

The procedures associated with the third and final decision point of the acquisition process are quite similar to the Milestone II procedures. The program estimate of the alternative selected becomes the new baseline in the updated DCP/IPS. Thresholds are also revised and a new SDDM issued. In the SAR, the revised baseline is referred to as the "production estimate" (PdE).

With the Milestone III decision made, the program proceeds into production. Unless problems occur during this phase that cause a DCP threshold to be exceeded, the program never returns to the (S)SARC or DSARC for another decision. However, progress of the program continues to be monitored by a review of the program continues to be monitored by review of the SAR until ninety percent of the production program is completed. At that time, the program manager can formally request authority to terminate SAR submissions.

B. VARIATIONS IN THE PROCESS

The acquisition managers may determine that a specific system program need not pass sequentially through all the phases of the process. Programs may also require major restructuring before a particular phase of the acquisition process is completed. Variations from the normal acquisition process are determined on a case-by-case basis.

C. THE A-X AS AN EXAMPLE OF DEFENSE SYSTEM ACQUISITION

No major weapon system acquisition program can be cited as a perfect example of compliance with the current process. The A-X (now A-10) Program does, however, exemplify the process. Hence, the events leading to its initiation are described herein for comparison with current requirements.

CONCEPT EXPLORATION

In December 1966, the Tactical Air Command forwarded a "Stated Operational Requirement" (SOR) for an aircraft to be designed for highly-survivable, heavily-armed, Close Air Support (CAS) of front-line troops.[1] This would lead to the first aircraft so specifically designed for the U.S. Air Force. (Today the Air Force would be required to submit a Justification for Major System New Start (JMSNS) together with its POM to document the need for the mission. Approval or modification of the POM submission by the Secretary of Defense (SECDEF) indicates validation of the need identified.)[2]

In the case of the A-X, the Request for Proposal (RFP) for design studies of CAS aircraft was circulated in March 1967. Following completion of the design studies, the RFP for

[1]Defense Marketing Service, *Military Aircraft*, 1979.

[2]DoDD 5000.1, Sec. E, paragraph 4a, p. 4.

prototyping went to twelve aircraft companies (in May 1970). Boeing, Cessna, Fairchild, General Dynamics, Lockheed and Northrop responded. In December, the Air Force tentatively selected Northrop to prototype two YA-9As, and Fairchild two YA-10As.

MILESTONE I--DEMONSTRATION AND VALIDATION

The Defense Systems Acquisition Review Council (DSARC) met on December 17, 1970 and approved the A-X Program for prototyping. (Note: the initial SAR was submitted as of 30 June 1971). A competitive fly-off of the Northrop and Fairchild demonstration vehicles was completed in December 1972.

MILESTONE II--FULL-SCALE DEVELOPMENT (FSD)

On January 17, 1973, the DSARC met to consider the Air Force selection of the Fairchild YA-10A as the winner and to approve the program for FSD. A Design-to-Cost (DTC) goal of $1,532,000 average unit flyaway cost (FY 1970 Constant Dollars), for 600 aircraft at a peak rate of 20 per month was also established. Formal SECDEF approval of the A-10 for FSD, including six pre-production aircraft, occurred January 18, 1973. The Development Estimate at the DSARC II became the baseline for the program.

MILESTONE III--PRODUCTION AND DEPLOYMENT

The Air Force returned to the DSARC on July 9, 1974 for approval of the A-10 for initial production. Long-lead procurement items were authorized on July 31, and after another DSARC meeting on November 19, 1974, SECDEF approved the first 22 production A-10As on December 19, 1974. The Air Force gave Fairchild a contract for this quantity on December 20. (Normally, a DSARC IIIB is held to go to rate production. In the

case of the A-10 Program, a Development Concept Paper (DCP 23)[1] was signed in lieu of DSARC IIIB on February 10, 1976).

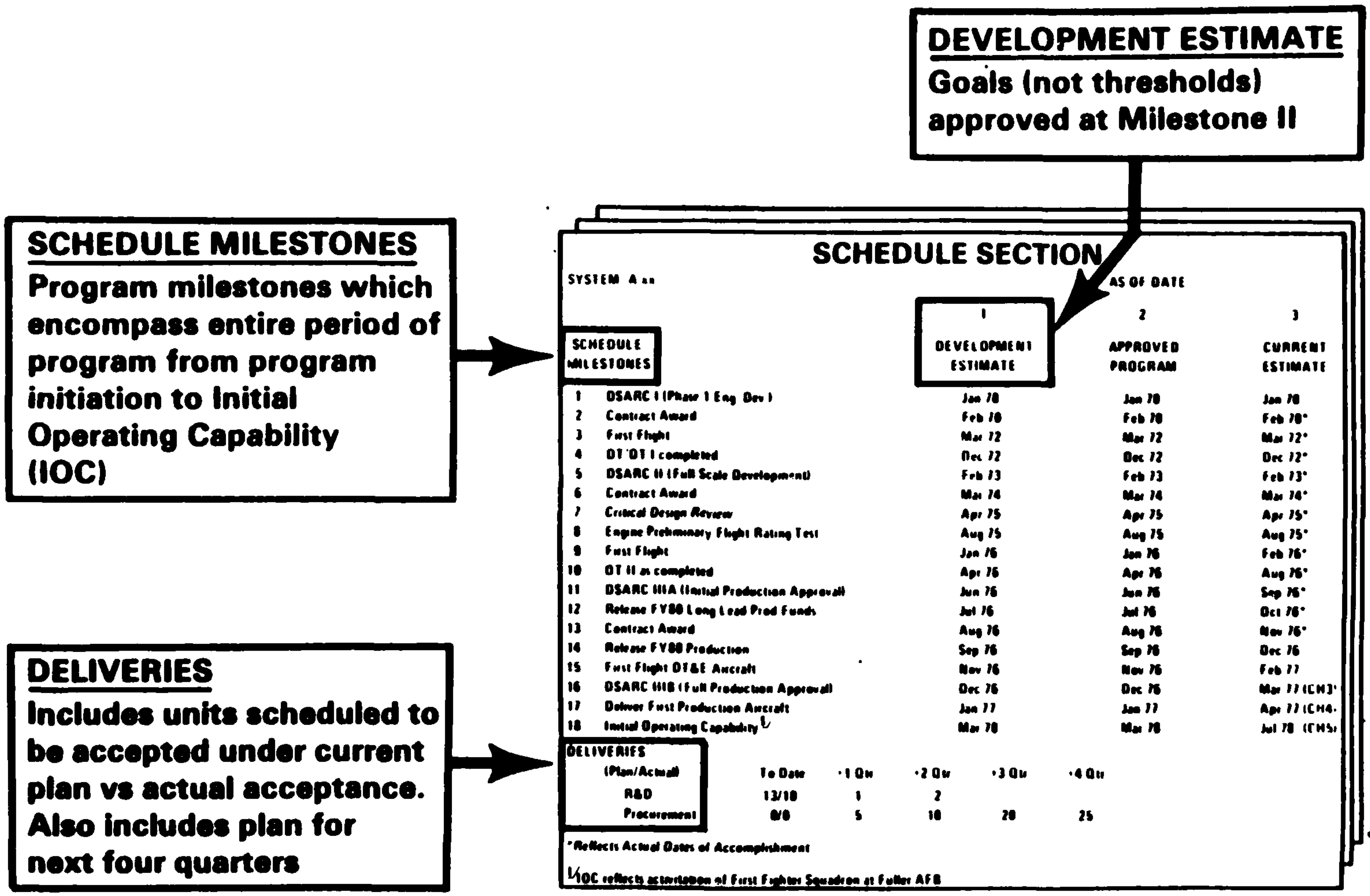
D. USE OF SELECTED ACQUISITION REPORT (SAR) DATA

The SAR is a standard, comprehensive, summary status report on DoD acquisition programs for management within the Department of Defense. As such, the SAR provides a definitive and standardized source of data that has proved to be invaluable in developing our proposed methodology for predicting probable schedule and cost growth during a major weapon system's acquisition cycle. The Program Manager prepares and the Services submit reports as of 31 March, 30 June, 30 September, and 31 December. The reports are forwarded through appropriate channels to the Assistant Secretary of Defense (Comptroller) for submission to Congress. The 31 December report is designated the comprehensive annual SAR; it is important because it coincides with the Presidential budget submission to the Congress. Thus, the Services and OSD must take care to ensure that the SAR data contained in the *Current Estimate (CE)* match budget items and the January Five-Year Defense Program (FYDP). The CE is the Service's latest forecast of the operational/technical characteristics, schedule, and program acquisition cost to acquire stated quantities. In accordance with the latest revision of DoDI 7000.3, the March, June, and September SARs are now abbreviated reports; they are submitted only when a change in the technical and operational characteristics, schedule milestones, or program cost has occurred since the most recent comprehensive annual or quarterly report. SARs, therefore, should support documentation and testimony already before the Congress.

[1]The "Development Concept Paper" is now called the Decision Coordinating Paper.

Internal DoD PPBS processes--e.g., the POM, PDM, October Budget Estimates Submission--may substantially change a particular SAR program, and/or the costs associated therewith. For these reasons, the December SARs submitted in earlier years were likely to be the only quarterly submissions that were a timely "snap-shot" of a program's status. Hence, our study effort focused on the data contained in the 31 December reports. Figure 2 is an example of a SAR Milestone Schedule and Figure 3 is an example of a SAR Annex, detailing a program's acquisition cost. A perusal of Figure 3 will quickly pinpoint one limitation of the SAR: the cost data presented in the report are highly aggregated. Admittedly, we would prefer a data source with much more detail available. We evaluated the potential of other documents such as the Decision Coordinating Paper and the Integrated Program Summary (IPS). We opted to use the SAR because of its visibility at decision-making levels and because it has a prescribed format common to all Services, which allows year-to-year comparisons to be made.

Schedule and cost data used in this study were extracted from the 31 December 1983 and earlier SARs.



SCHEDULE SECTION

SYSTEM A xx

SCHEDULE MILESTONES	AS OF DATE 1 DEVELOPMENT ESTIMATE	2 APPROVED PROGRAM	3 CURRENT ESTIMATE
1 DSARC I (Phase 1 Eng Dev)	Jan 70	Jan 70	Jan 70
2 Contract Award	Feb 70	Feb 70	Feb 70*
3 First Flight	Mar 72	Mar 72	Mar 72*
4 DT/OT I completed	Dec 72	Dec 72	Dec 72*
5 DSARC II (Full Scale Development)	Feb 73	Feb 73	Feb 73*
6 Contract Award	Mar 74	Mar 74	Mar 74*
7 Critical Design Review	Apr 75	Apr 75	Apr 75*
8 Engine Preliminary Flight Rating Test	Aug 75	Aug 75	Aug 75*
9 First Flight	Jan 76	Jan 76	Feb 76*
10 OT II as completed	Apr 76	Apr 76	Aug 76*
11 DSARC IIIA (Initial Production Approval)	Jun 76	Jun 76	Sep 76*
12 Release FY80 Long Lead Prod Funds	Jul 76	Jul 76	Oct 76*
13 Contract Award	Aug 76	Aug 76	Nov 76*
14 Release FY80 Production	Sep 76	Sep 76	Dec 76
15 First Flight DT&E Aircraft	Nov 76	Nov 76	Feb 77
16 DSARC IIIB (Full Production Approval)	Dec 76	Dec 76	Mar 77 (CH3)
17 Deliver First Production Aircraft	Jan 77	Jan 77	Apr 77 (CH4)
18 Initial Operating Capability 1/	Mar 78	Mar 78	Jul 78 (CH5)

DELIVERIES (Plan/Actual)	To Date	+1 Qtr	+2 Qtr	+3 Qtr	+4 Qtr
R&D	13/10	1	2		
Procurement	0/0	5	10	20	25

*Reflects Actual Dates of Accomplishment

1/ IOC reflects activation of First Fighter Squadron at Fuller AFB

Figure 2. SELECTED ACQUISITION REPORT FORMAT D--SCHEDULE MILESTONES

COLUMN 1 PLANNING/DEVELOPMENT/PRODUCTION ESTIMATE
Program cost baseline established at time of program approval (Milestone I, II, or III)

COMPREHENSIVE ANNUAL SELECTED ACQUISITION REPORT
SYSTEM: (DESIGNATION, such as, F-99A)

(Dollars in Millions) **AS OF DATE:** (Date, such as, December 31, 1981)
BASE YEAR: (YEAR, such as, FY 1979)

B. PROGRAM ACQUISITION COST

	(1) Planning/or Development/or Production Estimate (FY77-86)	(2) Changes	(3) Current Estimate (FY84-87)
1. Cost			
Development1	3,220.0	+30.5	3,230.5
Procurement2	11,751.4	+1,260.7	13,012.1
Airframe	6,708.1	+1,056.3	7,764.4
Engines	1,265.7	+ 72.1	1,337.8
Avionics	1,380.0	+ 90.2	1,470.2
Total flyaway	9,353.8	+1,218.6	10,572.4
Peculiar support equip.	1,040.0	-	1,040.0
Other weap. sys. cost	225.0	-	225.0
Initial spares	1,132.6	+ 42.1	1,174.7
Construction	250.0	+ 85.0	335.0
Total: constant FY79$	15,201.4	+1,376.2	16,577.6
Escalation	6,187.4	+2,718.3	8,905.7
Development	279.7	+33.4	313.1
Procurement	5,817.6	+2,611.0	8,428.6
Construction	90.1	+73.9	164.0
Total Program Cost	21,388.8	+4,094.5	25,483.3 (CN-81)
2. Quantities			
Development	4	-	4
Procurement	150	+10	160
Total	154	+10	164
3. Unit Cost			
Procurement:			
Constant FY79$	78.343	+2.983	81.326
Escalated	117.123	+16.881	134.004
Program:			
Constant FY79$	98.710	+2.372	101.082
Escalated	138.808	+16.498	155.306

Funding	(4) Current & Prior Yrs (FY77-82)	(5) Budget Year (FY83)	(6) Balance to Complete: FYDP (FY84-87)	(7) Balance to Complete: Beyond FYDP	(8) Total
Development	3,473.7	39.9	-	-	3,513.6
Procurement	2,024.3	3,448.1	15,948.0	-	21,400.7
Construction	171.8	327.2	-	-	499.0
Total	5,669.8	3,815.2	15,948.0		25,483.3 (CN-81)
Quantity					
Development	4	-	-	-	4
Procurement	10	20	130	-	160
Total	14	20	130	-	164

4. **Procurement Unit Cost Baseline for Current & Budget Years**

	FY82	FY83
Total Procurement Cost	2,050.0	3,448.1
Less CY Adv Proc	198.8	304.1
Plus PY Adv Proc	87.3	168.0
Net Total	1,938.5	3,312.0
Quantity	11	20
Procurement Unit Cost	176.227	165.600

5. **Approved Design to Cost Goal:**

	Average Flyaway Cost: Development Estimate3	Approved Program	Current Estimate	Latest Approved Threshold
QTY: 150; Peak Rate: 4/mo				
Constant FY79$	62.4	62.4	66.8	67.0
Escalated	93.8	93.8	109.9	110.0
QTY: 30; Peak Rate: 4/mo				
Constant FY79$	83.4	83.4	89.5	90.0
Escalated	113.6	113.6	133.2	134.0

6. **Foreign Military Sales:** Sales to date total 20 for Belgium for a total of $4 billion.

7. **Nuclear Costs:** None

1 Includes $300.0 in FY77 and $400.0 in FY78 actuals. $30.7 must be added to raise total pre-base year actuals to FY79$.

2 When the budget P-1 line does not include all Procurement Costs per DoD Instruction 5000.33 (reference j), such costs will be separately identified. Whether or not such costs are displayed as an "add" or "non-add" entry will be determined on a case by case basis. In general, those costs which are discretely identified to the major program will be displayed as "add" entries.

3 If the PE, DE, or PdE assumptions are different from the approved program assumptions, the differences should be identified.

Figure 3. COMPREHENSIVE ANNUAL SELECTED ACQUISITION REPORT FORMAT E--PROGRAM ACQUISITION COST

IV. SELECTED ACQUISITION REPORT (SAR) DATA

A. INTRODUCTION

During the research phase of this study, schedule and cost data on weapon systems were extracted from the SARs, separated into four weapon system categories (aircraft, missiles, ships, other) and subsequently analyzed. Our initial analysis of the data revealed that the SAR reporting process, while evolving over time, took on an added dimension in calendar year 1975. Prior to that, cost estimates were only expressed in current or "then year" dollars, with no common basis for year-to-year comparison. Commencing with the December 31, 1975 SAR and all subsequent submissions, program cost estimates are presented in both current and constant-year dollars, thus providing the requisite measure of comparability as well as a means to quickly assess the effects of inflation on a particular program. Constant dollar values will be used throughout this report. In those circumstances where data were extracted from pre-1975 SARs, the current dollar figures were escalated/de-escalated, as appropriate, to a given base-year constant dollar figure (i.e., the constant-year dollar base cited in 1975 and later SARs).

B. ISOLATING THE IMPACT OF INFLATION

Individual SARs reflect the estimated program costs in both constant and current dollars, the latter value being derived by adding actual and anticipated inflation costs to the constant dollar value of the estimate. Nowadays, it is not uncommon to discover that the original (base-year constant dollar) estimate

of a program's cost has more than doubled when examined in terms of today's value of the dollar (i.e., current dollar value). Although in this report we express cost values only in terms of constant dollars, we do, nevertheless, recognize and acknowledge that public pronouncements on cost growth in weapon system acquisition programs are usually made without adjusting for inflation (i.e., in current dollars). Given the normal development cycle for a new weapon system (ten or more years seems representative), the impact of inflation in a program can be severe. We would observe that since the DoD in and of itself cannot control inflation or its effects, it is more useful to focus on constant dollar growth as a more meaningful measure of management effectiveness in a particular program.

To maintain uniformity in the DoD budget process, the OSD Comptroller periodically updates escalation indices associated with a particular appropriation (RDT&E, MILCON, etc.). The indices are published several times during the fiscal year based on guidance received from the Office of Management and Budget (OMB) so that the stated budget requirements for a commodity or system will accurately reflect the current buying power of the dollar. A program manager normally maintains an audit trail of his program on a constant dollar basis; thus, in preparing a quarterly SAR submission he would use the indices to "inflate" his program's Current Estimate constant dollar costs to the corresponding current dollar value. The process whereby inflation indices are updated is the end product of a comprehensive effort to collect data from a myriad of sources within both the public (including each military service) and private sectors of the economy. One word of caution: The historical inflation experienced by one Service in a particular appropriation (e.g., aircraft procurement) may differ from that experienced by another Service.

C. DATA COLLECTION CHARTS

As an aid to more rigorous analysis, a simple graphing technique was employed to portray the schedule and cost growth during both the development and the procurement phases of a particular acquisition program. The development chart displayed the changes in the estimate of when the system would attain its Initial Operational Capability (IOC) and the growth, over time, in estimated development costs (RDT&E). See Fig. 4 for a sample development chart. The procurement chart captured the changes in the Procurement Unit Cost (PUC) and procurement quantities of the system as measured from the date of the Development Estimate (i.e., completion of MILESTONE II) through the IOC date and up to the present (or whenever the SAR reporting requirement for a particular system ceased). The Procurement Unit Cost is derived by dividing the total procurement costs (i.e., flyaway, other weapon system, and initial spares) by the quantity of systems to be procured. See Fig. 5 for a sample procurement chart. Although a majority of earlier studies of cost growth opted to analyze growth on a "Program Acquisition Cost" basis, this study has elected to examine the program in more detail by segregating the development cost from the procurement cost growth patterns. It should be understood, however, that the Program Acquisition Cost is simply the sum of the development, procurement and military construction costs.

During the course of our investigations, a total of 52 systems which had achieved IOC were selected for detailed analysis. Each system was assigned to one of four materiel categories: aircraft, missiles, ships, and other. We anticipate that in future updates of this paper, when additional systems currently under development reach IOC, the category "other" will be replaced by two new categories: command, control, communications and intelligence (C^3I) and tracked vehicles and other weapons. For purposes of exposition,

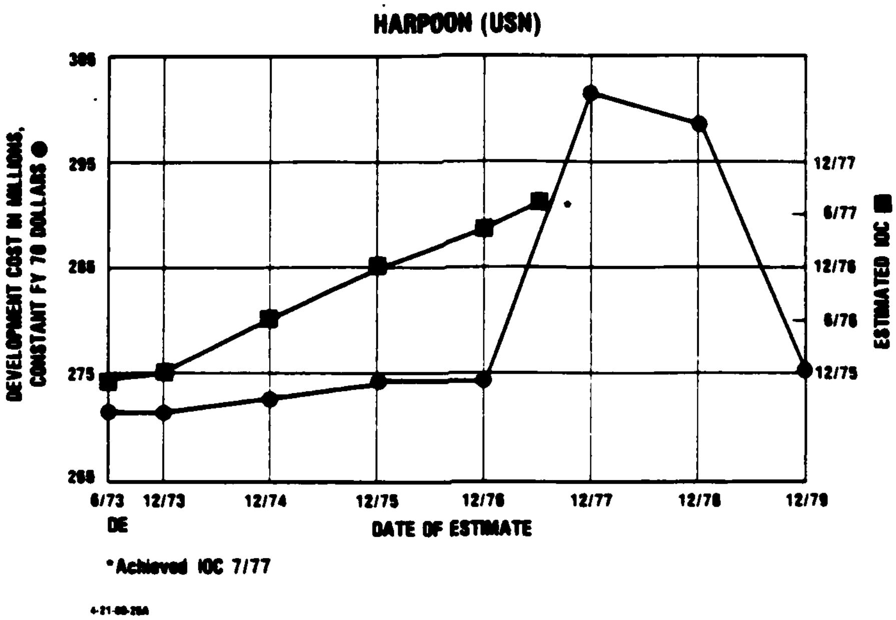


Figure 4. SAMPLE DEVELOPMENT COST CHART

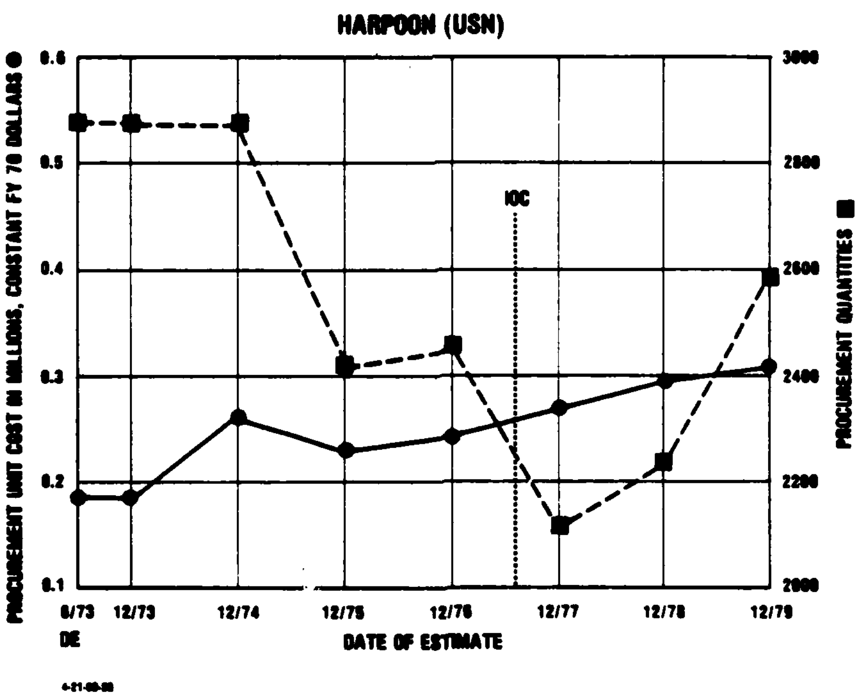


Figure 5. SAMPLE PROCUREMENT UNIT COST CHART

primary focus was placed on the missile systems. The charts that had been developed earlier (Figs. 4 and 5) were then re-checked to see if any apparent anomalies existed in the data that might prejudice use of the data as a predictor of future growth. For example, in the area of procurement unit costs one would intuitively expect that the PUC would increase significantly if the procurement quantities were cut. Likewise, one would anticipate that a significant increase in quantity would reduce the PUC, or at least hold the cost constant from one year to the next. In the case of the U.S. Air Force Short-Range Attack Missile (SRAM), the latter expectation did not hold--at one point prior to IOC the procurement quantities increased by a factor of 2.7 and the procurement unit costs increased by a factor of 4.3. Unfortunately, the SRAM was an early program that reached IOC in August 1972. The data and analyses presented in the SRAM SAR were quite sketchy. A massive cost increase (by a factor of 7.6 times the Development Estimate of procurement costs) was attributed to an "Estimating Change." Unable to isolate the actual factors involved in the SRAM developmental history, we elected to exclude SRAM data from any further consideration. It must be reiterated, however, that the basic aim of this paper is to develop schedule and cost growth factors, and not to delve into the reasons for growth. We must also point out that the estimated cost data contained in SAR reports are *not* normalized (i.e., adjusted for quantity changes). Given this fact and recognizing the virtual impossibility of accurately predicting probable future quantity changes in a given weapon system procurement program, we elected to pursue the development of our methodology without relying on normalized cost/quantity data. This decision was reinforced by our initial findings, which are discussed in the following section.

D. INITIAL FINDINGS

After the development and procurement charts were completed, they were reviewed to determine if any trends could be discerned. This initial inspection of the charts led to two findings:

1. Achievement of IOC marks the end of significant growth in both development and procurement costs for most systems. (Note: the IOC date is usually the last schedule milestone subject to a DCP threshold restriction).

2. Procurement quantities are approximately as likely to increase as they are to decrease. For 52 programs at or beyond IOC, procurement quantities increased from the development estimate in 26 cases, decreased in 21 cases, and remained unchanged in five cases (see Table 1). This finding is at variance with the commonly held belief that as the acquisition cycle evolves, smaller quantities of systems are procured than planned earlier because of the effects of schedule/cost growth and constrained budgets. However, it should be noted that the Army tended to procure fewer quantities than planned, while the Navy tended to procure more. The same procurement quantity growth factors, grouped by type of system (at IOC and latest SAR) and by Service, are summarized as follows:

PROCUREMENT QUANTITY GROWTH FACTORS
AT SYSTEM IOC DATE

	<1.0	1.0	>1.0
Aircraft	3	3	6
Missiles	12	4	10
Ships	3	1	5
Other	2	0	3
Total	20	8	24

PROCUREMENT QUANTITY GROWTH FACTORS
BASED ON LATEST SAR

	<1.0	1.0	>1.0
Aircraft	3	2	7
Missiles	12	2	12
Ships	3	1	5
Other	3	0	2
Total	21	5	26

PROCUREMENT QUANTITY GROWTH FACTORS
BASED ON LATEST SAR BY SERVICE

	<1.0	1.0	>1.0
Army	8	3	3
Navy	8	1	18
Air Force	5	1	5
Total	21	5	26

Table 1. PROCUREMENT QUANTITY GROWTH FACTORS--PROGRAMS AT OR BEYOND IOC (AS OF DECEMBER 1983)

Service	System	Procurement Quantity Growth Factors			
		Planning Estimate	Development Estimate	IOC	Latest SAR
Army	AN/TTC-39	-	1.00	0.57	0.57
	COPPERHEAD	-	1.00	0.07	0.23
	DRAGON	-	1.00	0.35	0.27
	I-HAWK	1.01	1.00	0.61	0.86
	LANCE	-	1.00	1.00	2.00
	M-1 Tank	-	1.00	2.13	2.13
	M-198	-	1.00	0.96	0.59
	MLRS	-	1.00	1.00	1.00
	PATRIOT	1.59	1.00	0.62	0.62
	PERSHING II	-	1.00	1.00	1.00
	STINGER	-	1.00	1.33	2.01
	TACFIRE	-	1.00	1.02	0.92
	TOW	-	1.00	0.48	0.59
	UH-60	-	1.00	1.00	1.00
Air Force	A-10	1.00	1.00	1.01	0.99
	ALCM	-	1.00	0.44	0.51
	E-3A	-	1.00	0.74	0.74
	E-4	-	1.00	0.83	0.50
	EF-111A	-	1.00	1.00	1.00
	F-15	-	1.00	1.00	1.86
	F-16	-	1.00	2.14	4.08
	GLCM	-	1.00	0.80	0.80
	MAVERICK (A/B)	-	1.00	1.29	1.18
	MINUTEMAN II	-	1.00	0.95	1.13
	SRAM	-	.00	2.14	2.14

Table 1 (continued)

Service	System	Procurement Quantity Growth Factors			
		Planning Estimate	Development Estimate	IOC	Latest SAR
Navy	CAPTOR	-	1.00	0.15	0.41
	CG-47 AEGIS	-	1.00	1.63	1.63
	CH-53E	-	1.00	2.29	2.29
	CVAN 68	-	1.00	1.00	1.00
	DD 963	-	1.00	1.03	1.03
	DLGN-38	1.33	1.00	1.33	1.33
	E-2C	-	1.00	1.68	3.61
	F-14	-	1.00	0.70	1.80
	F-18	-	1.00	1.71	1.71
	FFG-7	-	1.00	1.10	1.02
	HARM	-	1.00	1.21	1.21
	HARPOON	1.46	1.00	0.73	1.31
	LHA	-	1.00	0.56	0.56
	MK-48	-	1.00	1.00	0.68
	NATO PHM	-	1.00	0.18	0.18
	PHALANX	-	1.00	1.26	1.07
	PHOENIX	-	1.00	1.07	1.46
	POSEIDON	-	1.00	1.01	0.95
	P-3C	-	1.00	1.85	3.04
	SIDEWINDER AIM-9L	-	1.00	1.18	1.14
	SIDEWINDER AIM-9M	-	1.00	1.57	1.72
	SPARROW AIM-7F	-	1.00	0.63	0.90
	SPARROW AIM-7M	-	1.00	1.26	1.26
	SSN-688	-	1.00	1.22	2.00
	TOMAHAWK	-	1.00	3.69	3.69
	TRIDENT I Missile	-	1.00	0.94	0.47
	TRIDENT Submarine	-	1.00	0.80	0.80

E. SCHEDULE GROWTH

Schedule growth during development of a new weapon system is normally measured by the amount of slippage experienced in a program between a fixed base date (e.g., the approval date of either the Planning Estimate or the Development Estimate) and the attainment of the system's Initial Operational Capability. To avoid confusion, schedule growth discussed in this report will use the IOC date established at the time of Development Estimate approval as the base date. All systems in each of the four weapon system categories were analyzed individually. After the necessary data were collected, the cumulative total growth factor was computed using the following formula:

$$\text{Cumulative total growth factor} = \frac{\text{Actual time (in years) from DE approval to IOC}}{\text{Initial estimated time (in years) from DE approval to IOC}}$$

Table 2 displays schedule data, by category, for the systems analyzed. Median and mean values for the various categories are also summarized. We recommend more weight be given to median values than to mean values in our cost growth methodology. As can be seen in Table 2 (Aircraft), a single program (i.e., CH-53E) can have an undue effect on mean values.

As an example, within the missile category, the schedule growth ranged from zero growth for the MINUTEMAN III and MK-48 Torpedo programs to a growth of 7.2 years above the initial estimate of the time interval between the date of Development Estimate approval and the initially estimated date of IOC attainment for the SPARROW AIM-7F program. The actual time required to attain IOC, as measured from the date of DE approval, ranged from 0.7 years for the MK-48 to 11 years for the PHOENIX. The median and mean values for this time interval were 5.8 and 6.0 years, respectively.

Table 2. SYSTEM SCHEDULE GROWTH

Category	System	Time					
		Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate to Est. IOC	Years--Dev. Estimate to Actual IOC	Cumulative Total Growth Factor
Aircraft	A-10	5/71	6/77	10/77	6.1	6.4	1.05
	CH-53E	3/73	7/77	5/83	4.3	10.2	2.37
	E-2C	4/68	11/73	2/74	5.6	5.8	1.04
	E-3A	6/71	3/77	4/78	5.8	6.8	1.18
	E-4	1/73	6/74	5/75	1.4	2.3	1.64
	EF-111A	1/75	4/80	12/83	5.3	8.9	1.68
	F-14	1/69	4/73	12/73	4.3	4.9	1.14
	F-15	1/70	7/75	9/75	5.5	5.7	1.04
	F-16	3/75	10/80	10/80	5.6	5.6	1.00
	F-18	12/75	9/82	3/83	6.8	7.3	1.07
	P-3C	6/67	3/70	7/70	2.8	3.1	1.11
	UH-60	6/71	6/79	11/79	8.0	8.4	1.05
	Median				5.6	6.1	1.09
	Mean				5.1	6.3	1.28
Missiles	ALCM	1/77	6/81	12/82	4.4	5.9	1.34
	CAPTOR	6/71	9/76	7/79	5.3	8.1	1.54
	COPPERHEAD	6/75	11/79	12/82	4.4	7.5	1.70
	DRAGON	7/65	5/70	9/74	4.8	9.2	1.92
	GLCM	1/77	5/82	12/83	5.3	6.9	1.30
	HARM	2/78	10/81	11/83	3.7	5.8	1.57
	HARPOON	6/73	11/75	7/77	2.4	4.1	1.71

Table 2 (continued)

Category	System	Time					
		Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate to Est. IOC	Years--Dev. Estimate to Actual IOC	Cumulative Total Growth Factor
Missiles (Cont'd)	I-HAWK	12/68	4/71	11/72	2.4	3.9	1.63
	LANCE	6/67	6/70	6/72	3.0	5.0	1.67
	MK-48	6/71	2/72	2/72	0.7	0.7	1.00
	MAVERICK (A/B)	7/68	12/71	2/73	3.4	4.6	1.35
	MINUTEMAN III	3/68	6/70	6/70	2.3	2.3	1.00
	MLRS	4/77	11/82	3/83	5.6	5.9	1.05
	PATRIOT	3/72	12/80	2/83	8.8	10.9	1.24
	PERSHING II	12/78	12/84	12/83	6.0	5.0	0.83
	PHOENIX	12/62	4/73	12/73	10.3	11.0	1.07
	POSEIDON	11/66	11/70	3/71	4.0	4.3	1.08
	SIDEWINDER AIM-9L (N)	1/71	3/74	5/78	3.2	7.3	2.28
	SIDEWINDER AIM-9M (N)	3/78	8/82	9/82	4.4	4.5	1.02
	SPARROW AIM-7F (N)[a]	6/68	1/69	4/76	0.6[a]	7.8[a]	13.00[a]
	SPARROW AIM-7M (N)	4/78	7/81	1/83	3.3	4.8	1.45
	SRAM	12/66	2/70	8/72	3.2	5.7	1.78
	STINGER	5/72	9/77	2/81	5.3	8.8	1.66
	TOMAHAWK	1/77	12/81	4/83	4.9	6.3	1.29
	TOW	5/66	8/68	9/70	2.3	4.3	1.87
	TRIDENT I	10/73	10/78	10/79	5.0	6.0	1.20
	Median				4.0	5.8	1.35
	Mean				4.3	6.0	1.42

[a]Values not used to calculate the Mean.

Table 2 (continued)

Category	System	Time					
		Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate to Est. IOC	Years--Dev. Estimate to Actual IOC	Cumulative Total Growth Factor
Ships	CG-47 AEGIS	1/78	3/84	9/83	6.2	5.7	0.92
	CVAN 68	12/67	3/73	3/76	5.3	8.3	1.57
	DD 963	6/70	6/75	6/77	5.0	7.0	1.40
	DLGN-38	12/71	12/75	9/77	4.0	5.8	1.44
	FFG-7	10/72	5/78	3/79	5.6	6.4	1.14
	LHA	12/68	2/74	5/77	5.2	8.4	1.62
	NATO PHM	9/72	3/76	5/78	3.5	5.7	1.63
	SSN-688	1/72	9/74	11/76	3.7	5.8	1.57
	TRIDENT Submarine	10/73	10/78	10/82	5.0	9.0	1.80
	Median				5.0	6.4	1.57
	Mean				4.8	6.9	1.45
Other	AN/TTC-39	7/74	3/81	3/83	6.7	8.7	1.30
	M-1 Tank	12/76	6/80	1/81	3.5	4.1	1.17
	M-198	12/71	5/77	4/79	5.4	7.3	1.35
	TACFIRE	12/67	7/74	4/79	6.6	11.3	1.71
	PHALANX	1/73	1/77	8/79	4.0	6.6	1.65
	Median				5.4	7.3	1.35
	Mean				5.2	7.6	1.44

The median cumulative total schedule growth amounted to 1.35 times the initial estimate of the time interval between approval of the DE and the anticipated IOC date.

Rounding out our analysis of schedule growth, we developed composite graphs that plotted the changes in the estimated time required to achieve IOC for each individual system over time--extending from the date of DE approval until the actual date of IOC achievement (see Figs. 6 through 9).[1] On each graph the median slope for that materiel category was plotted. We examined the actual shape of the schedule growth curves to determine if there were any specific types of curves associated with a particular weapon system category. We posited three types of growth curves and their properties:

- Convex: Early program slippage, with growth leveling off prior to IOC.
- Straight Line: Relatively uniform growth throughout the program.
- Concave: Little if any growth early in the program, preponderance of growth later in program up to and including IOC attainment.

We decided that there was no clear trend toward either convexity or concavity for any of the categories, and that a straight-line projection will adequately approximate the probable growth a specific program may experience. The details of the schedule growth projection methodology will be discussed in Chapter V.

[1]To avoid crowding, the missiles attaining IOC in 1983 were plotted separately. Note that their median slope (1.29) was considerably less than that of the earlier missiles (1.63).

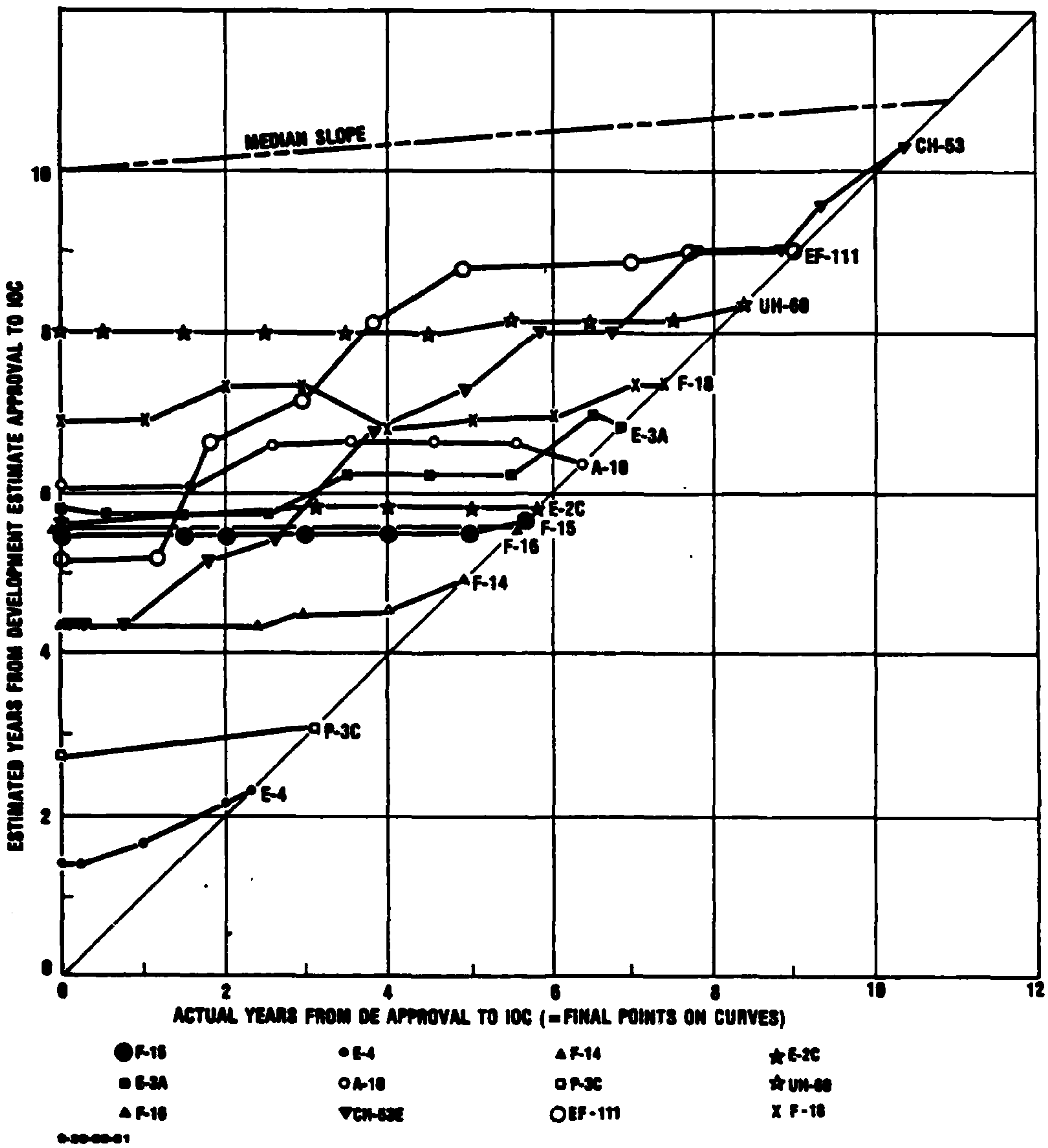


Figure 6. SCHEDULE GROWTH, AIRCRAFT

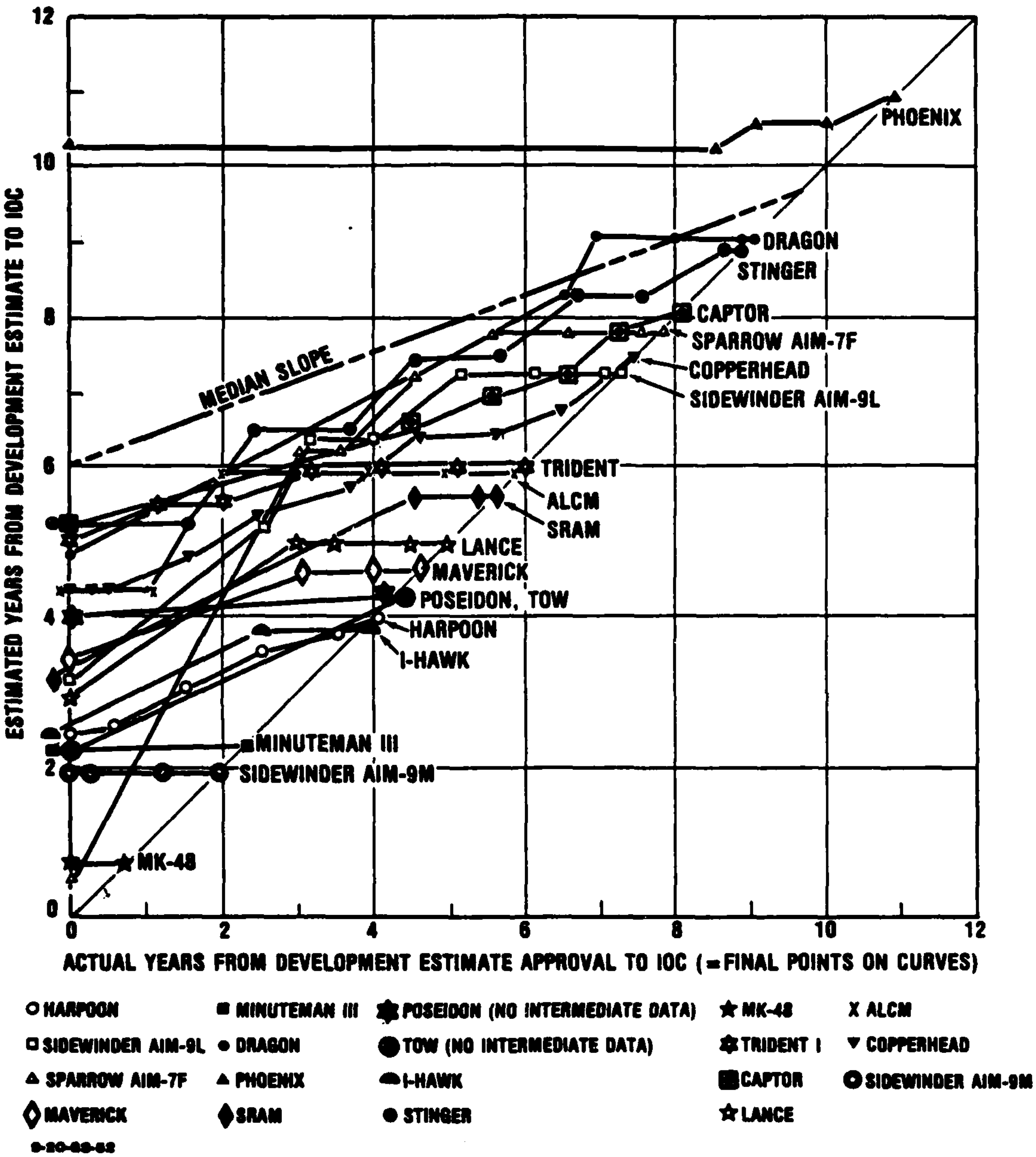


Figure 7a. SCHEDULE GROWTH, MISSILES IOC PRIOR TO 1983

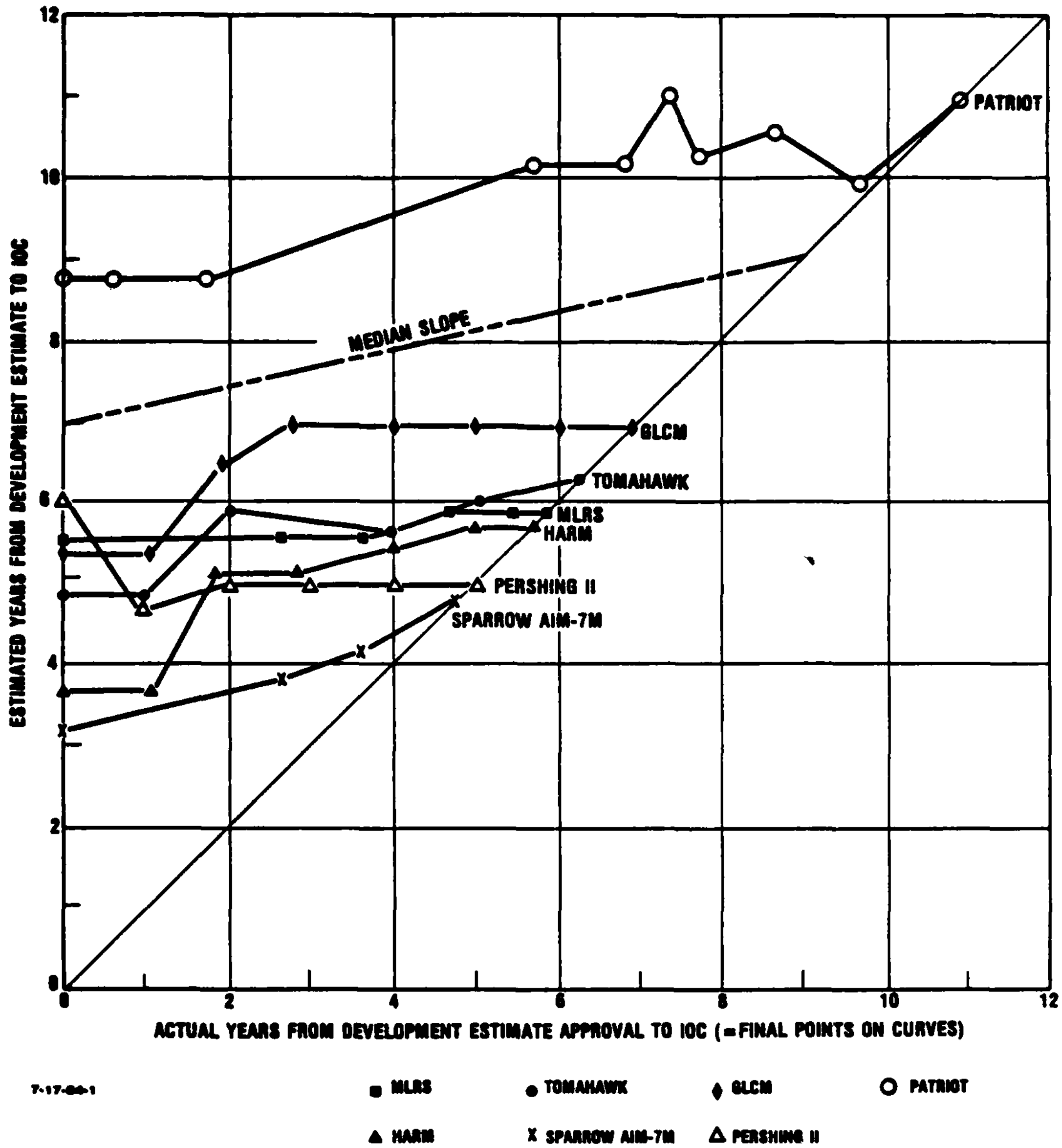


Figure 7b. SCHEDULE GROWTH, MISSILES IOC IN 1983

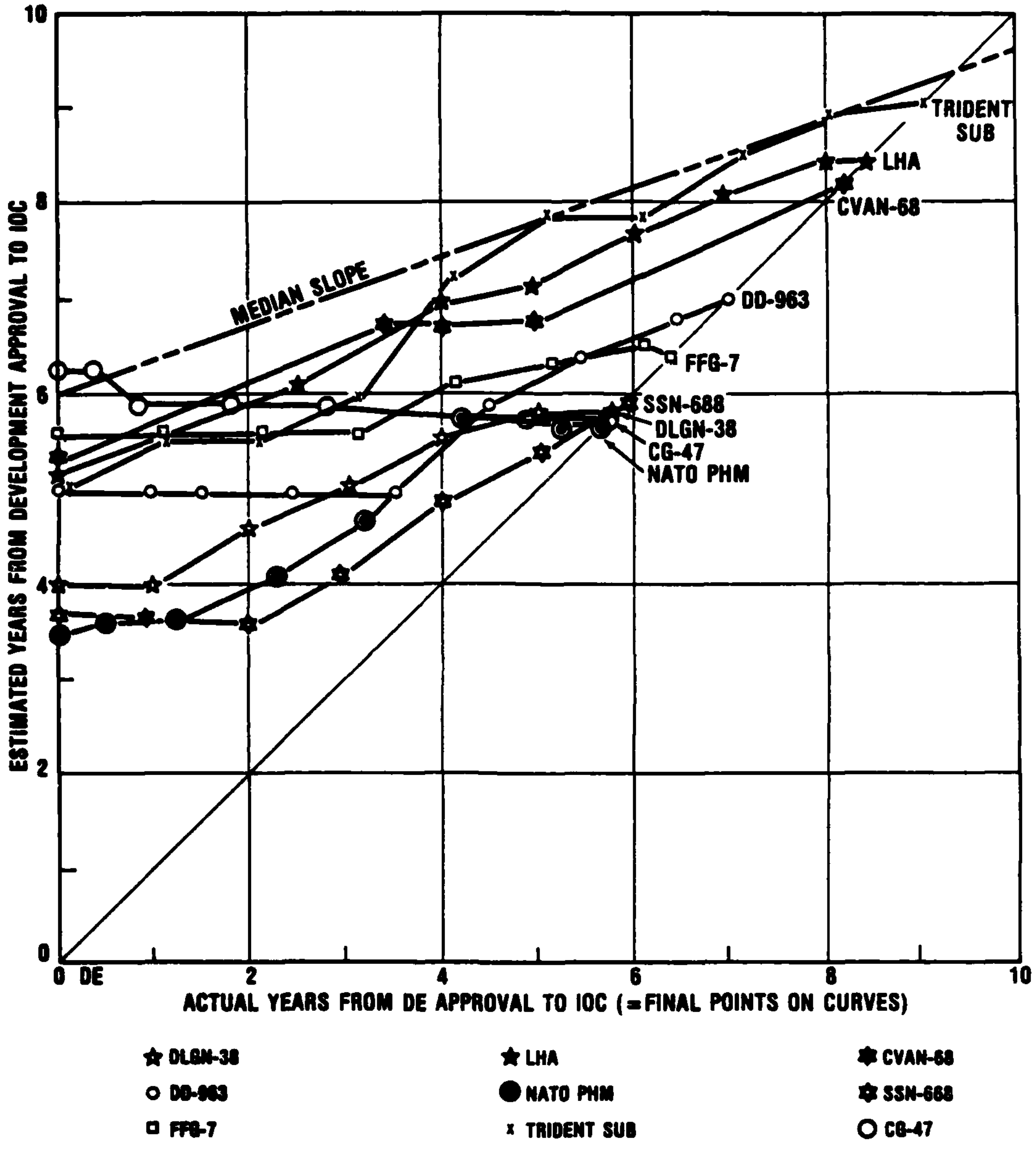


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Figure 8. SCHEDULE GROWTH, SHIPS

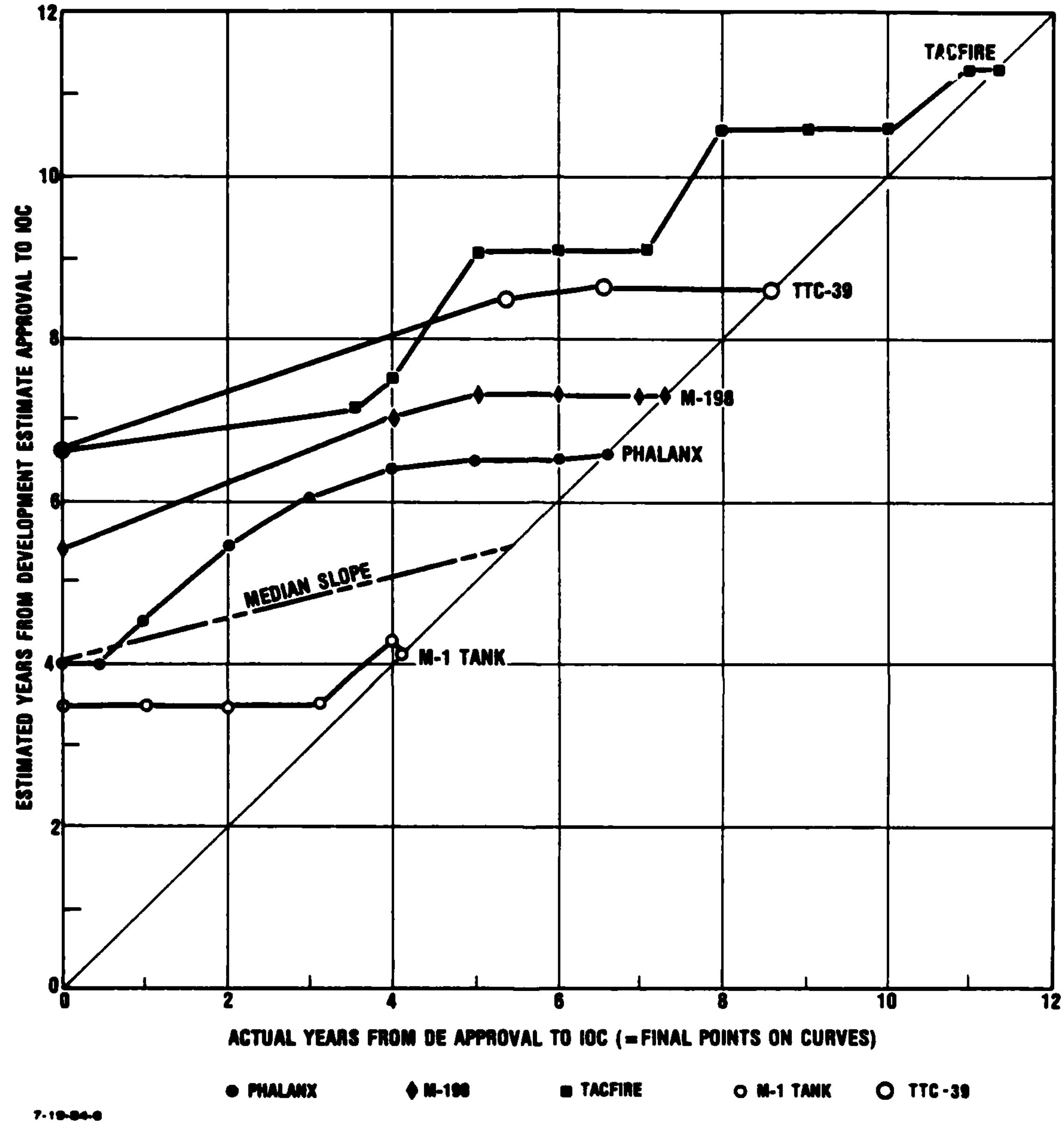

Figure 9. SCHEDULE GROWTH, OTHER

F. COST GROWTH

The techniques applied in our analysis of weapon system cost growth are similar to those used in our investigation of schedule growth. Cumulative total and cumulative average development cost and procurement unit cost growth factors were computed for each of the four weapon system categories using the following formulas:

$$\text{Cumulative total} = \frac{\text{Estimated (x or y) at IOC date}}{\text{Estimated (x or y) at DE approval date}}$$

$$\text{Cumulative average} = \sqrt[n]{\text{Cumulative total growth factor}}$$

where x = Development Cost
y = Procurement Unit Cost
n = Time interval (in years) from date of Development Estimate approval to actual IOC date.

To test the validity of our earlier finding that IOC marks the end of significant cost growth for a weapon system acquisition program, the cumulative total and the cumulative average growth patterns for post-IOC development and procurement costs were examined. The growth rates were computed using the formulas:

$$\text{Cumulative total} = \frac{\text{Estimated (x or y) in latest SAR}}{\text{Estimated (x or y) at IOC date}}$$

$$\text{Cumulative average} = \sqrt[t]{\text{Cumulative total growth factor}}$$

where x = Development Cost
y = Procurement Unit Cost
t = Time interval (in years) from IOC date to latest SAR estimate.

Table 3 (Development Cost) and Table 4 (Procurement Unit Cost) display the post-IOC cumulative total and cumulative average cost growth factors. These tables confirm that cost growth after IOC is much lower than prior IOC. In our cost growth methodology we ignore post-IOC cost growth.

Figures 10 through 17 are plots of the estimated development and procurement unit costs for each of the four materiel categories. Note that these figures are plotted on semi-logarithmic scales. Therefore, within each figure the same slope anywhere on the figure implies the same cumulative average cost growth factor. Because we are ignoring post-IOC cost growth, each curve ends with the SAR cost following achievement of IOC. On each graph, the median slope for that materiel system category was plotted using the median cumulative average growth factor from Tables 3 or 4, as appropriate.

To avoid crowding, the missiles attaining IOC in 1983 were again plotted separately. The cumulative average growth factors for the different groups of missiles are as follows:

Development Cost	
IOC Prior to 1983	1.030
IOC in 1983	1.038
All missiles	1.034
Procurement Unit Cost	
IOC Prior to 1983	1.073
IOC in 1983	1.054
All missiles	1.072

The choice of growth factors is left to the user of this paper. However, we recommend a factor based on more missiles than those reaching IOC in 1983 be used (7 missiles).

Table 3. DEVELOPMENT COST GROWTH FOR SYSTEMS ANALYZED

Category	System	Base Year	Estimated Development Costs (Millions of Base Year Constant $)			Growth Factors		
						Development Estimate Approval Date to IOC Date		IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Aircraft	A-10	1970	281.9	335.0	359.5	1.188	1.027	1.073
	CH-53E	1973	93.5	179.1	179.1	1.916	1.066	1.000
	E-2C	1968	129.3	196.4	220.9	1.519	1.074	1.125
	E-3A	1970	761.0	1,178.8	1,299.4	1.549	1.058	1.102
	E-4	1974	158.8	293.5	299.6	1.848	1.306	1.021
	EF-111A	1973	84.3	176.9	176.9	2.098	1.087	1.000
	F-14	1969	899.5	1,367.5	1,922.5	1.520	1.089	1.406
	F-15	1970	1,654.9	1,869.7	2,079.7	1.130	1.021	1.112
	F-16	1975	578.6	789.2	912.3	1.364	1.057	1.156
	F-18	1975	1,437.7	1,650.2	1,650.2	1.148	1.019	1.000
	P-3C	1968	203.0	210.4	248.1	1.036	1.012	1.179
	UH-60	1971	357.3	365.8	386.4	1.024	1.003	1.056
	Median					1.442	1.058	1.088
	Mean					1.445	1.068	1.103
Missiles	ALCM	1977	694.0	1,011.7	986.3	1.458	1.066	0.975
	CAPTOR	1971	85.5	100.3	102.5	1.173	1.020	1.022
	COPPERHEAD	1975	104.9	130.7	130.2	1.246	1.030	0.996
	DRAGON	1966	61.7	116.9	116.3	1.895	1.072	0.995
	GLCM	1977	74.8	260.1	260.1	3.477	1.198	1.000
	HARM	1978	216.5	343.0	343.0	1.584	1.083	1.000

Table 3 (continued)

Category	System	Base Year	Estimated Development Costs (Millions of Base Year Constant $)			Growth Factors		
						Development Estimate Approval Date to IOC Date		IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Missiles (Cont'd)	HARPOON	1970	272.0	301.7	268.0	1.109	1.026	0.888
	I-HAWK	1969	95.5	106.6	145.5	1.116	1.029	1.365
	LANCE	1970	349.0	356.1	349.0	1.020	1.004	0.980
	MK-48	1972	150.4	155.8	275.9	1.036	1.052	1.771
	MAVERICK (A/B)	1968	115.7	124.9	120.7	1.079	1.017	0.966
	MINUTEMAN III	1967	1,835.4	1,846.4	1,800.0	1.006	1.003	0.975
	MLRS	1978	261.3	265.7	265.7	1.017	1.003	1.000
	PATRIOT	1972	1,078.4	1,618.2	1,618.2	1.501	1.038	1.000
	PERSHING II	1979	570.4	570.0	570.0	0.999	0.999	1.000
	PHOENIX	1963	94.0	144.3	121.8	1.535	1.040	0.844
	POSEIDON[a]	Current $	1,221.1	1,303.8	1,300.2	1.067[a]	1.015[a]	0.997[a]
	SIDEWINDER AIM-9L (N)	1971	6.6	44.8	44.6	6.788	1.300	0.996
	SIDEWINDER AIM-9M (N)	1976	25.3	68.9	64.8	2.723	1.249	0.940
	SPARROW AIM-7F (N)	1968	24.9	80.2	91.4	3.221	1.162	1.140
	SPARROW AIM-7M (N)	1978	51.61	51.0	51.0	0.988	0.998	1.000
	SRAM[a]	Current $	167.6	464.5	453.8	2.771[a]	1.196[a]	0.979[a]
	STINGER	1972	76.4	163.6	177.5	2.141	1.053	1.091
	TOMAHAWK	1977	782.8	1,205.0	1,205.0	1.539	1.071	1.000
	TOW	1966	97.9	101.9	117.7	1.041	1.009	1.155
	TRIDENT I	1974	2,794.1	2,935.4	2,916.8	1.051	1.008	0.994
	Median					1.210	1.034	1.000
	Mean					1.739	1.064	1.046

[a]Data not used to compute Median/Mean.

Table 3 (continued)

Category	System	Base Year	Estimated Development Costs (Millions of Base Year Constant $)			Growth Factors: Development Estimate Approval Date to IOC Date		Growth Factors: IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Ships	CG-47 AEGIS	1978	55.5	73.5	73.5	1.324	1.051	1.000
	CVAN 68	1967	No Development Funds					
	DD 963	1970	36.0	37.6	38.3	1.044	1.008	1.019
	DLGN-38	1970	21.2	21.2	21.2	1.000	1.000	1.000
	FFG-7	1973	14.1	20.1	20.0	1.426	1.056	0.995
	LHA	1969	22.3	22.2	22.2	0.996	0.999	1.000
	NATO PHM	1973	70.5	82.7	82.7	1.173	1.028	1.000
	SSN-688	1971	0.0	4.8	32.8	-	-	6.833
	TRIDENT Submarine	1974	576.4	682.9	682.9	1.185	1.019	1.000
	Median					1.173	1.019	1.000
	Mean					1.164	1.023	1.731
Other	M-1 Tank	1972	422.6	597.3	648.8	1.413	1.088	1.086
	M-198	1972	30.9	41.7	41.7	1.350	1.042	1.000
	PHALANX	1972	38.8	113.4	113.6	2.923	1.174	1.002
	TACFIRE	1968	50.8	77.0	77.0	1.516	1.037	1.000
	TTC-39	1974	129.0	199.0	199.0	1.543	1.051	1.000
	Median					1.516	1.051	1.000
	Mean					1.749	1.078	1.018

Table 4. PROCUREMENT UNIT COST GROWTH FOR SYSTEMS ANALYZED

Category	System	Base Year	Estimated Procurement Unit Costs (Millions of Base Year Constant $)			Growth Factors		
						Development Estimate Approval Date to IOC Date		IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Aircraft	A-10	1970	2.04	2.60	2.78	1.275	1.039	1.069
	CH-53E	1973	5.3	7.49	7.49	1.413	1.034	1.000
	E-2C	1968	14.36	19.74	15.83	1.375	1.055	0.802
	E-3A	1970	33.1	43.9	42.89	1.326	1.042	0.977
	E-4	1974	42.5	47.9	32.9	1.127	1.053	0.687
	EF-111 A	1973	7.36	11.36	11.36	1.543	1.050	1.000
	F-14	1969	9.7	12.3	13.13	1.268	1.050	1.067
	F-15	1970	5.94	7.29	8.00	1.227	1.037	1.097
	F-16	1975	5.84	6.45	6.94	1.104	1.018	1.076
	F-18	1975	8.19	9.21	9.21	1.125	1.016	1.000
	P-3C	1968	10.49	11.14	10.36	1.062	1.020	0.930
	UH-60	1971	1.43	1.55	1.85	1.084	1.010	1.194
	MEDIAN					1.248	1.038	1.000
	MEAN					1.244	1.035	0.992
Missiles	ALCM	1977	0.675	1.021	0.969	1.513	1.073	0.949
	CAPTOR	1971	0.036	0.184	0.158	5.111	1.226	0.850
	COPPERHEAD	1975	0.00556	0.0313	0.0231	5.629	1.259	0.738
	DRAGON	1966	0.00113	0.003	0.00298	2.666	1.112	0.992
	GLCM	1977	1.333	2.671	2.671	2.004	1.106	1.000
	HARM	1978	0.115	0.172	0.172	1.496	1.072	1.000
	HARPOON	1970	0.182	0.269	0.361	1.478	1.100	1.342
	I-HAWK	1969	0.0459	0.0736	0.071	1.603	1.129	0.965
	LANCE	1970	0.105	0.122	0.126	1.162	1.031	1.033
	MK-48	1972	0.372	0.368	0.367	0.989	0.985	0.997
	MAVERICK (A/B)	1968	0.0126	0.0151	0.0122	1.198	1.040	0.808
	MINUTEMAN III	1967	3.95	5.96	4.05	1.509	1.201	0.680
	MLRS	1978	0.00448	0.00355	0.00355	0.792	0.961	1.000
	PATRIOT	1972	0.100	0.175	0.175	1.750	1.053	1.000

Table 4 (continued)

Category	System	Base Year	Estimated Procurement Unit Costs (Millions of Base Year Constant $)			Growth Factors		
						Development Estimate Approval Date to IOC Date		IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Missiles (Cont'd)	PERSHING II	1979	1.169	2.253	2.253	1.927	1.160	1.000
	PHOENIX	1963	0.189	0.335	0.537	1.772	1.053	1.603
	POSEIDON[a]	Current $	3.425	4.183	4.177	1.221[a]	1.048[a]	0.999[a]
	SIDEWINDER AIM-9L (N)	1971	0.023	0.038	0.045	1.652	1.071	1.184
	SIDEWINDER AIM-9M (N)	1976	0.038	0.034	0.040	0.895	0.976	1.176
	SPARROW AIM-7F (N)	1968	0.04	0.066	0.061	1.650	1.066	0.924
	SPARROW AIM-7M (N)	1978	0.080	0.103	0.108	1.288	1.054	1.049
	SRAM[a]	Current $	0.09	0.441	0.423	4.900[a]	1.322[a]	0.959[a]
	STINGER	1972	0.0134	0.0256	0.0224	1.910	1.076	0.875
	TOMAHAWK	1977	0.946	1.172	1.172	1.239	1.035	1.00
	TOW	1966	0.00197	0.00385	0.003025	1.954	1.169	0.787
	TRIDENT I	1974	6.20	5.59	7.079	0.902	0.983	1.266
	MEDIAN					1.558	1.072	1.000
	MEAN					1.837	1.082	1.009
Ships	CG-47 AEGIS	1978	546.7	587.06	587.06	1.074	1.013	1.000
	CVAN 68	1967	504.9	584.1	590.6	1.160	1.018	1.011
	CVAN 69[b]	1967	475.8	607.6	604.9	1.277[b]	1.022[b]	0.996[b]
	DD 963	1970	78.62	83.0	85.48	1.060	1.008	1.030
	DLGN-38	1973	215.1	235.5	238.5	1.095	1.016	1.013
	FFG-7	1973	52.13	89.15	88.04	1.710	1.086	0.988
	LHA	1969	141.0	222.8	242.94	1.580	1.056	1.090
	NATO PHM	1973	20.5	39.8	45.3	1.941	1.123	1.138

[a]Data not used to compute Median/Mean.

[b]Data presented for information only. Values not used to calculate median/mean.

Table 4 (continued)

Category	System	Base Year	Estimated Procurement Unit Costs (Millions of Base Year Constant $)			Growth Factors		
						Development Estimate Approval Date to IOC Date		IOC Date to Latest SAR
			At Development Estimate Approval Date	At IOC	Latest SAR	Cumulative Total	Cumulative Average	Cumulative Total
Ships (Cont'd)	SSN-688	1971	160.2	144.9	182.45	0.904	0.983	1.259
	TRIDENT Submarine	1974	517.3	649.51	642.96	1.256	1.026	0.990
	MEDIAN					1.160	1.018	1.013
	MEAN					1.309	1.037	1.058
Other	M-1 TANK	1972	0.595	0.638	0.784	1.072	1.017	1.229
	M-198	1972	0.123	0.150	0.170	1.219	1.028	1.133
	PHALANX	1972	1.185	1.645	1.463	1.388	1.050	0.889
	TACFIRE	1968	0.695	1.436	1.558	2.066	1.066	1.085
	TTC-39	1974	1.769	2.086	2.086	1.179	1.019	1.000
	MEDIAN					1.219	1.028	1.085
	MEAN					1.385	1.036	1.067

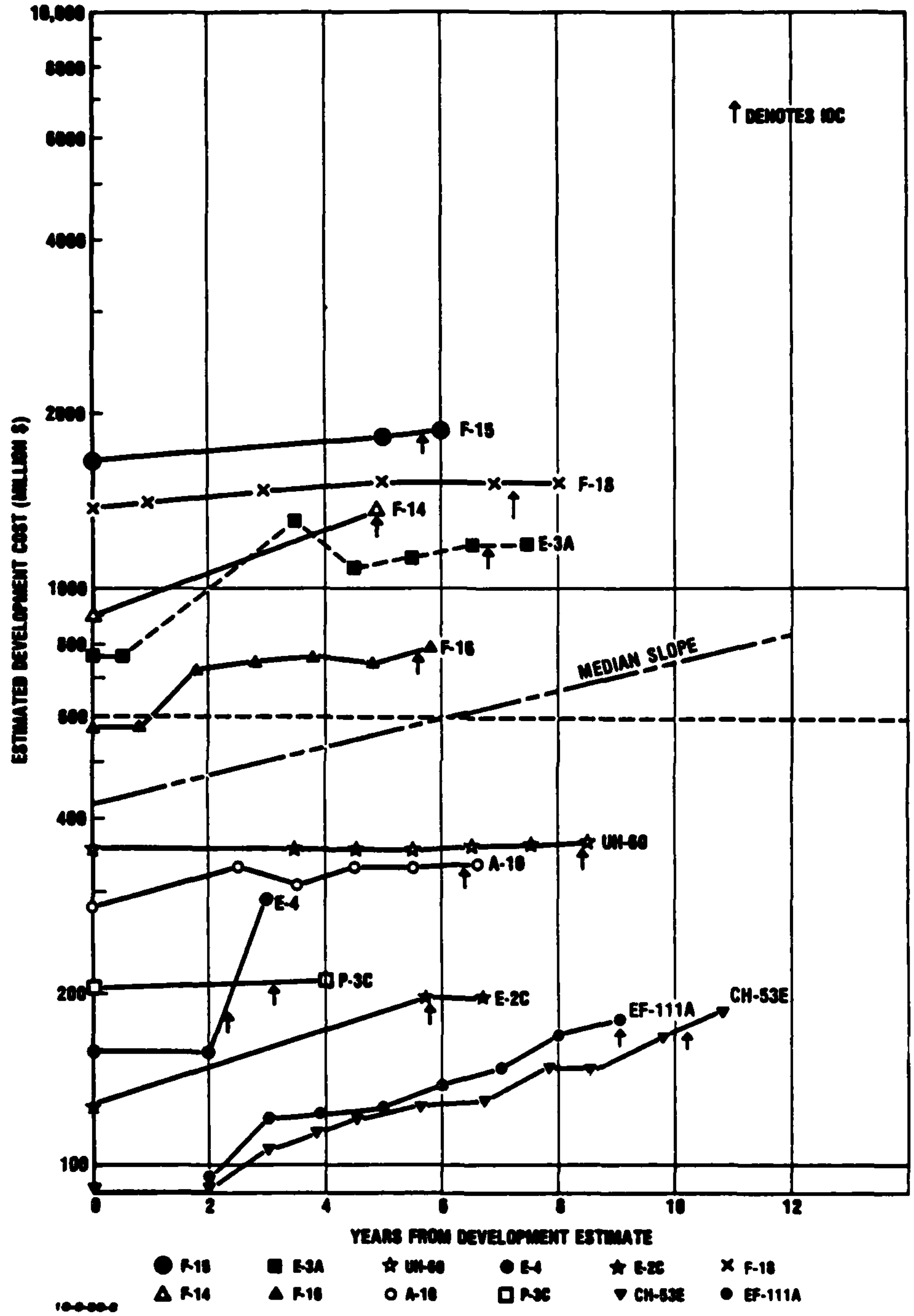

Figure 10. DEVELOPMENT COST GROWTH, AIRCRAFT

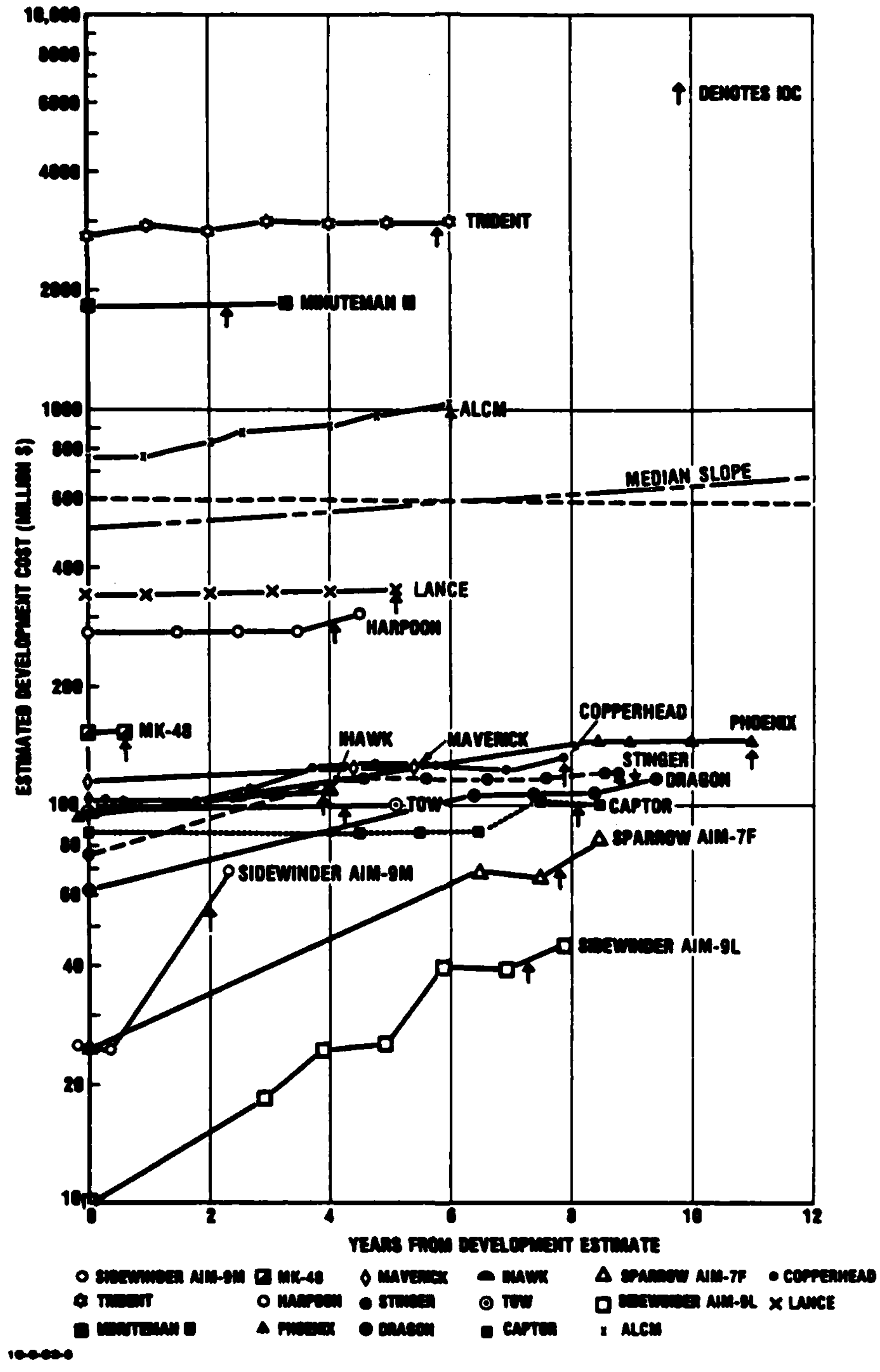

Figure 11a. DEVELOPMENT COST GROWTH, MISSILES IOC PRIOR TO 1983

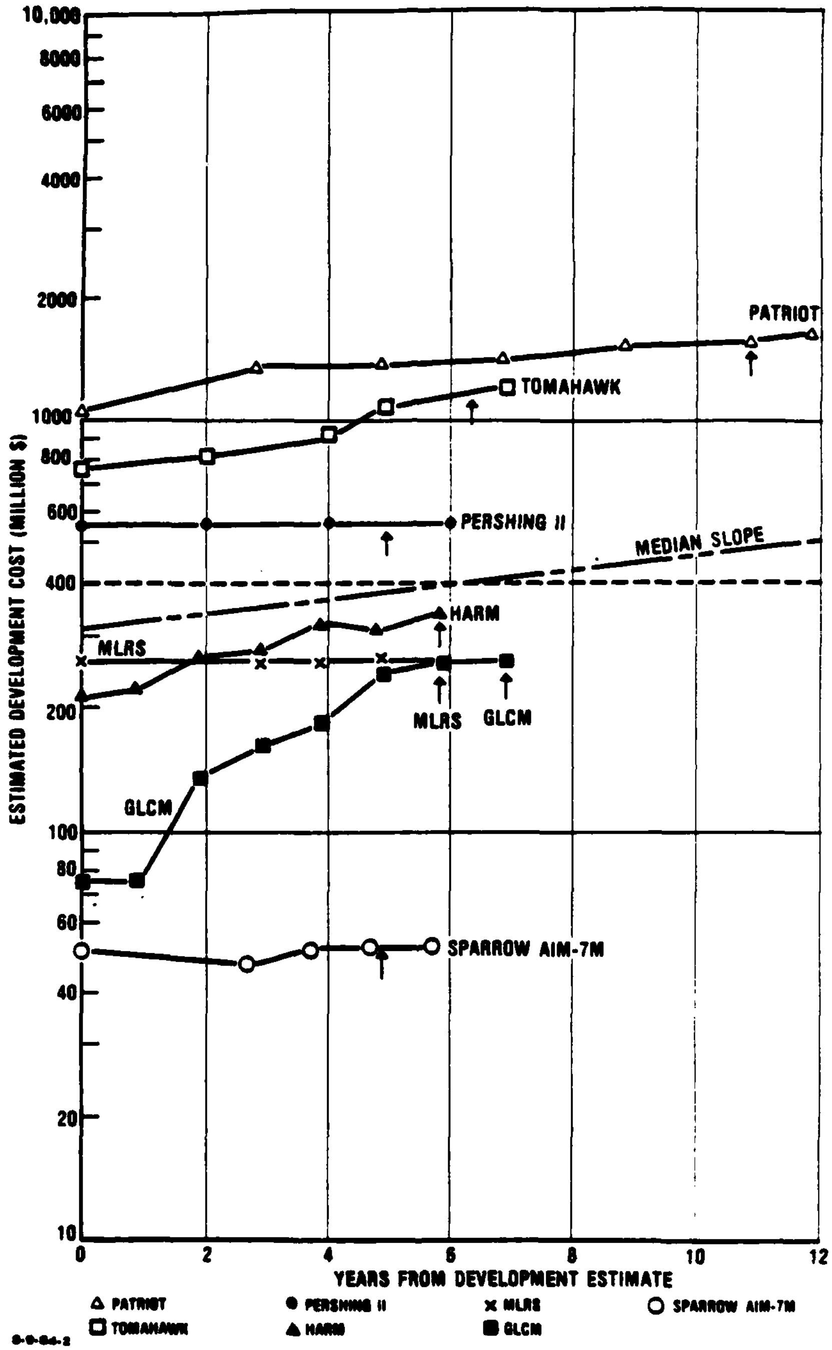

Figure 11b. DEVELOPMENT COST GROWTH, MISSILES IOC IN 1983

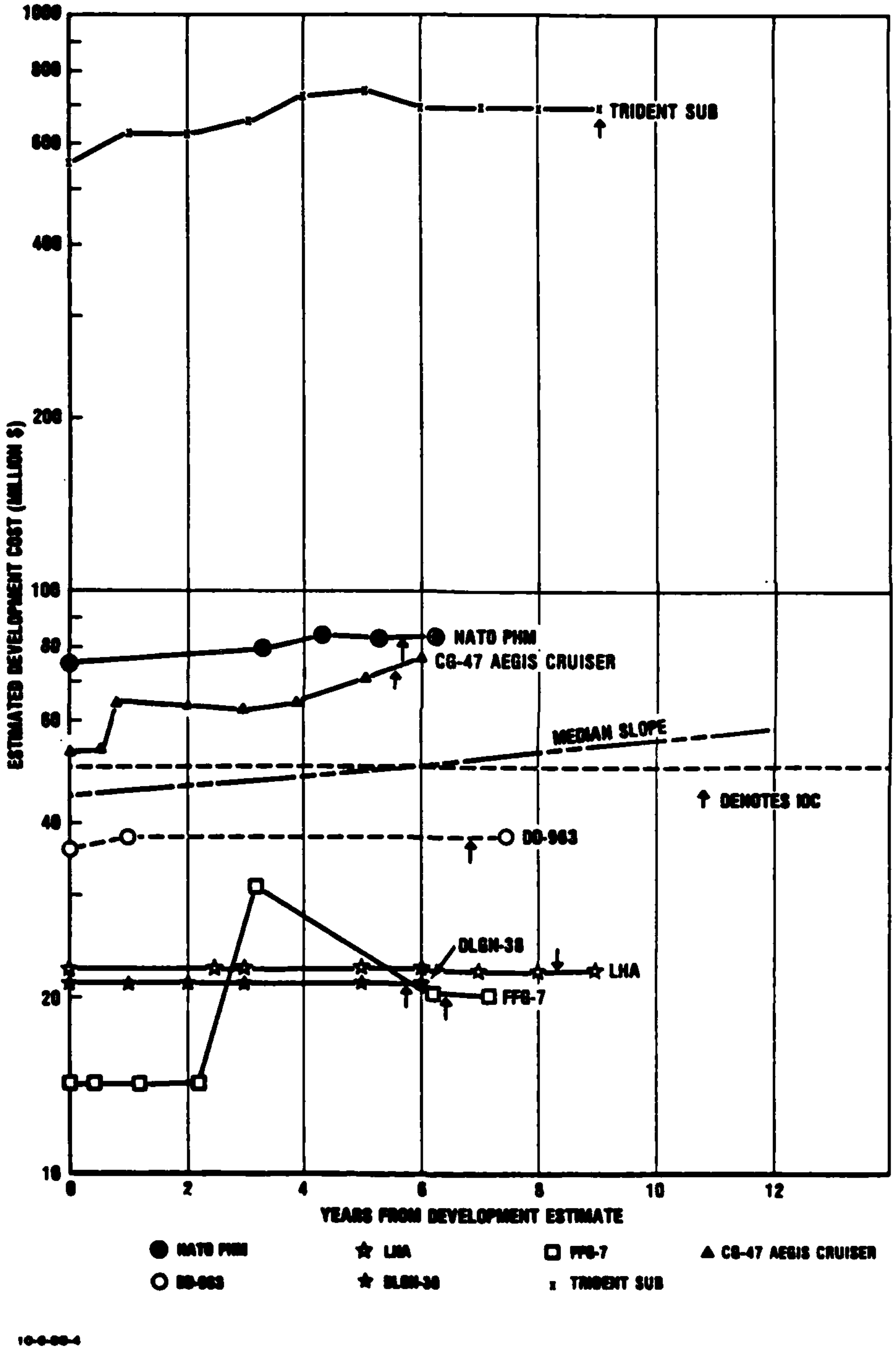

Figure 12. DEVELOPMENT COST GROWTH, SHIPS

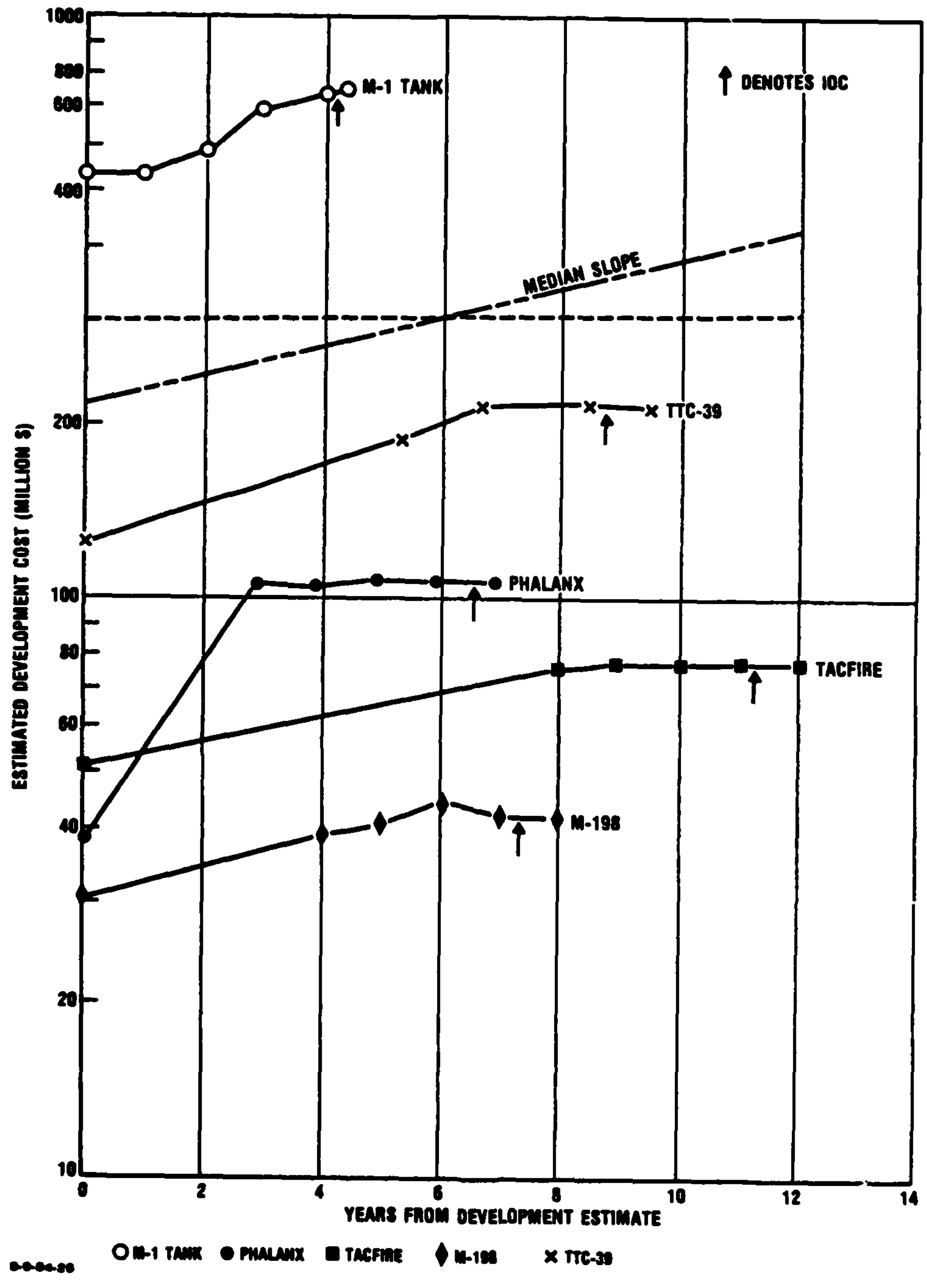

Figure 13. DEVELOPMENT COST GROWTH, OTHER

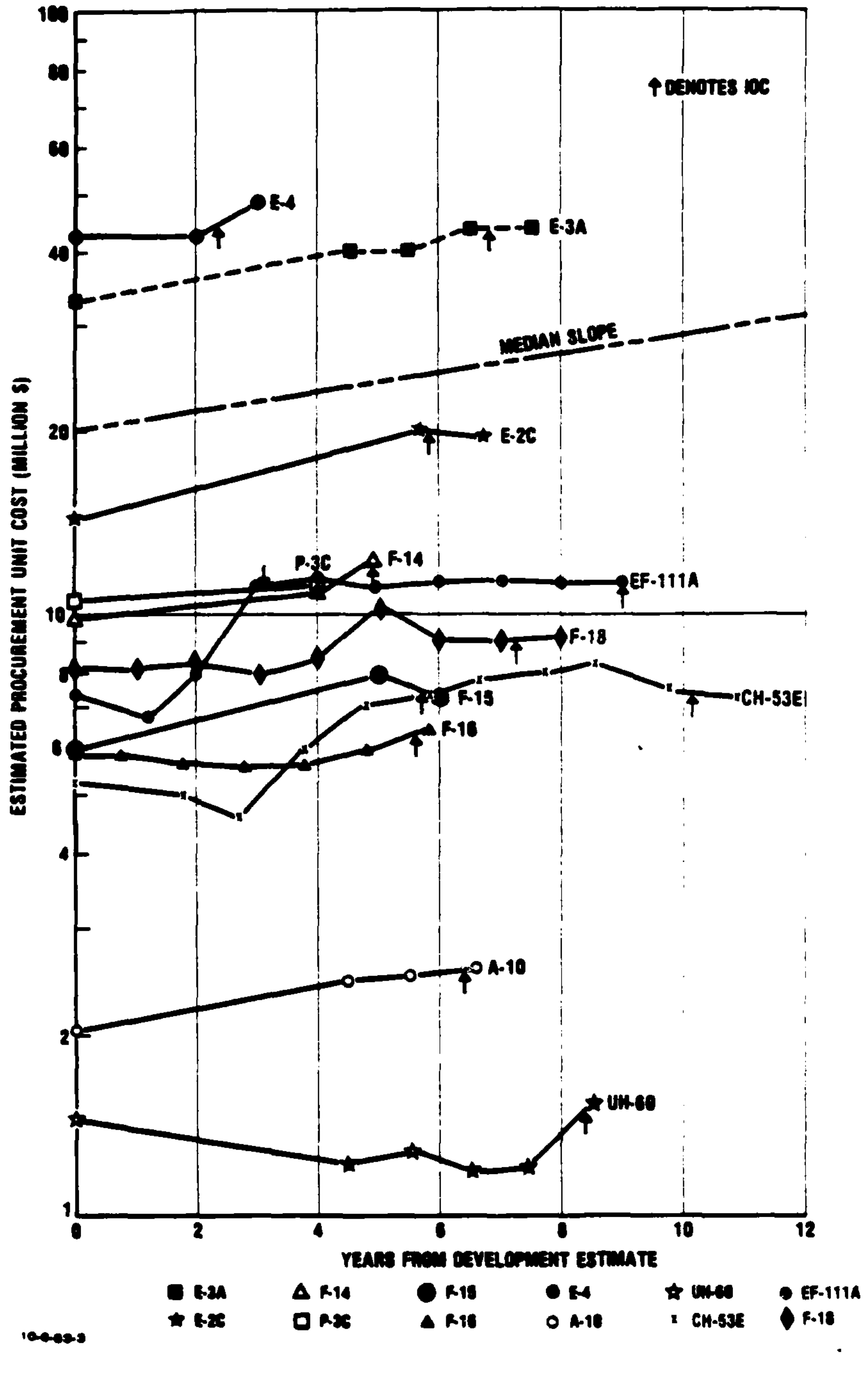

Figure 14. PROCUREMENT UNIT COST GROWTH, AIRCRAFT

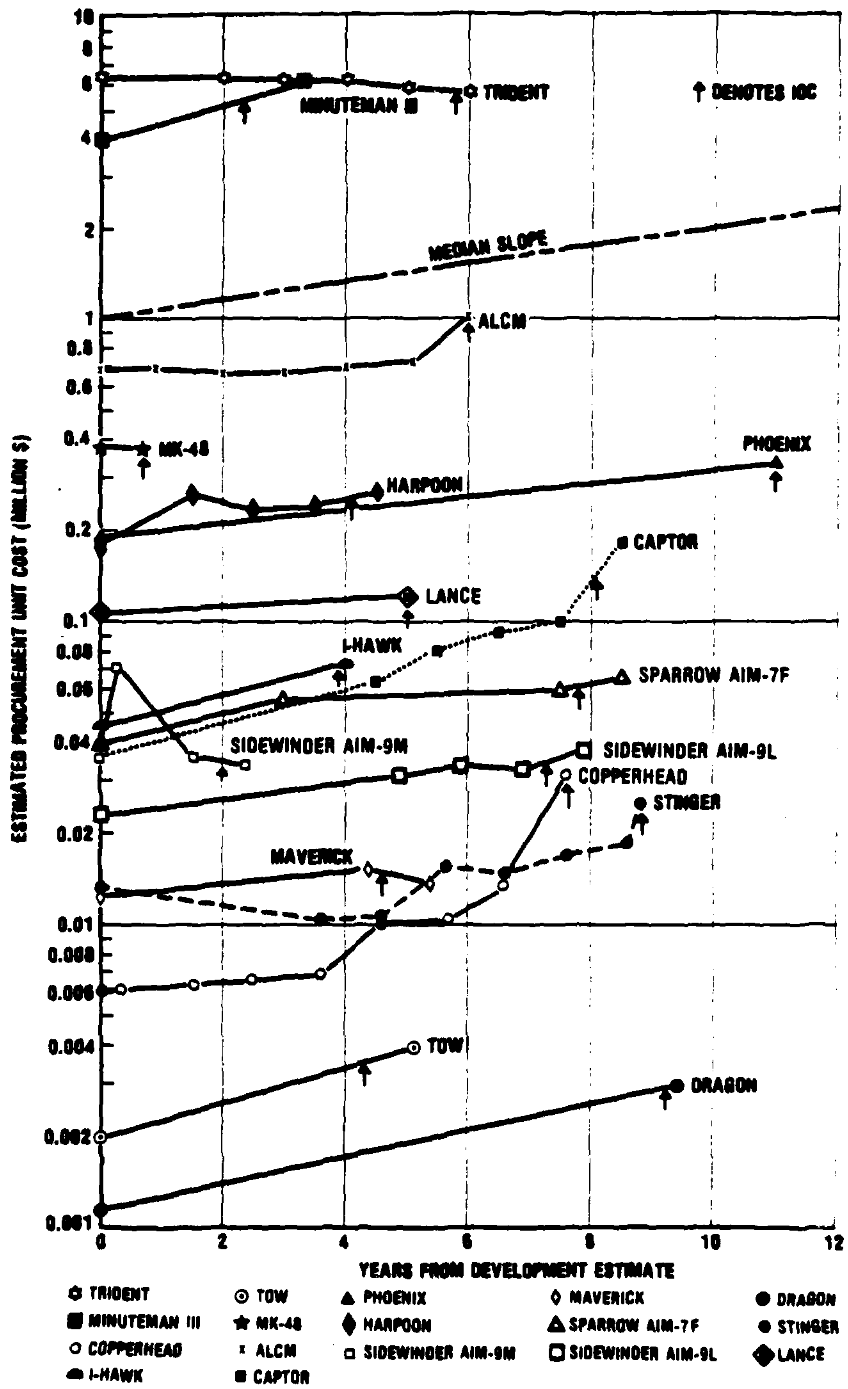

Figure 15a. PROCUREMENT UNIT COST GROWTH, MISSILES IOC PRIOR TO 1983

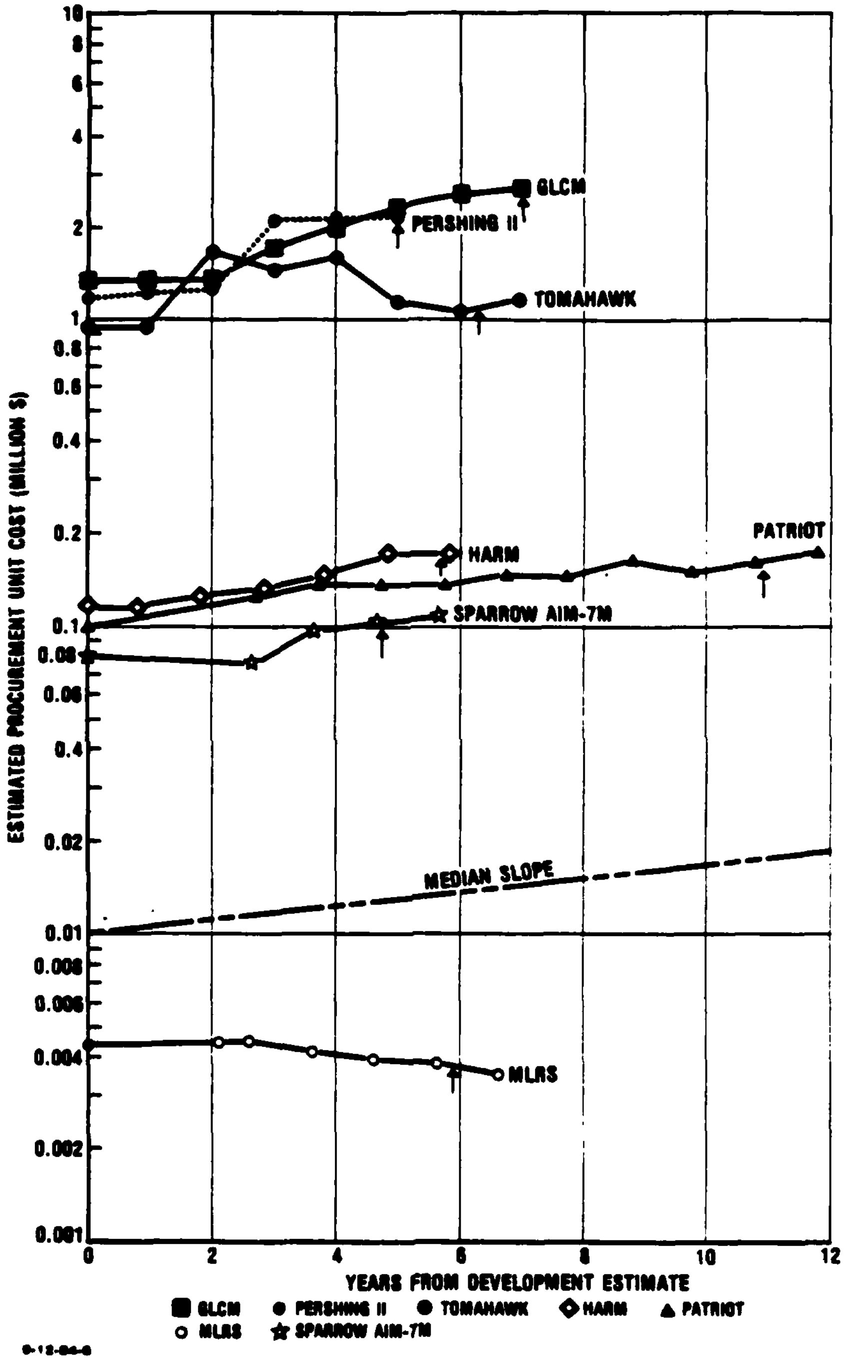

Figure 15b. PROCUREMENT UNIT COST GROWTH, MISSILES (concluded) IOC IN 1983

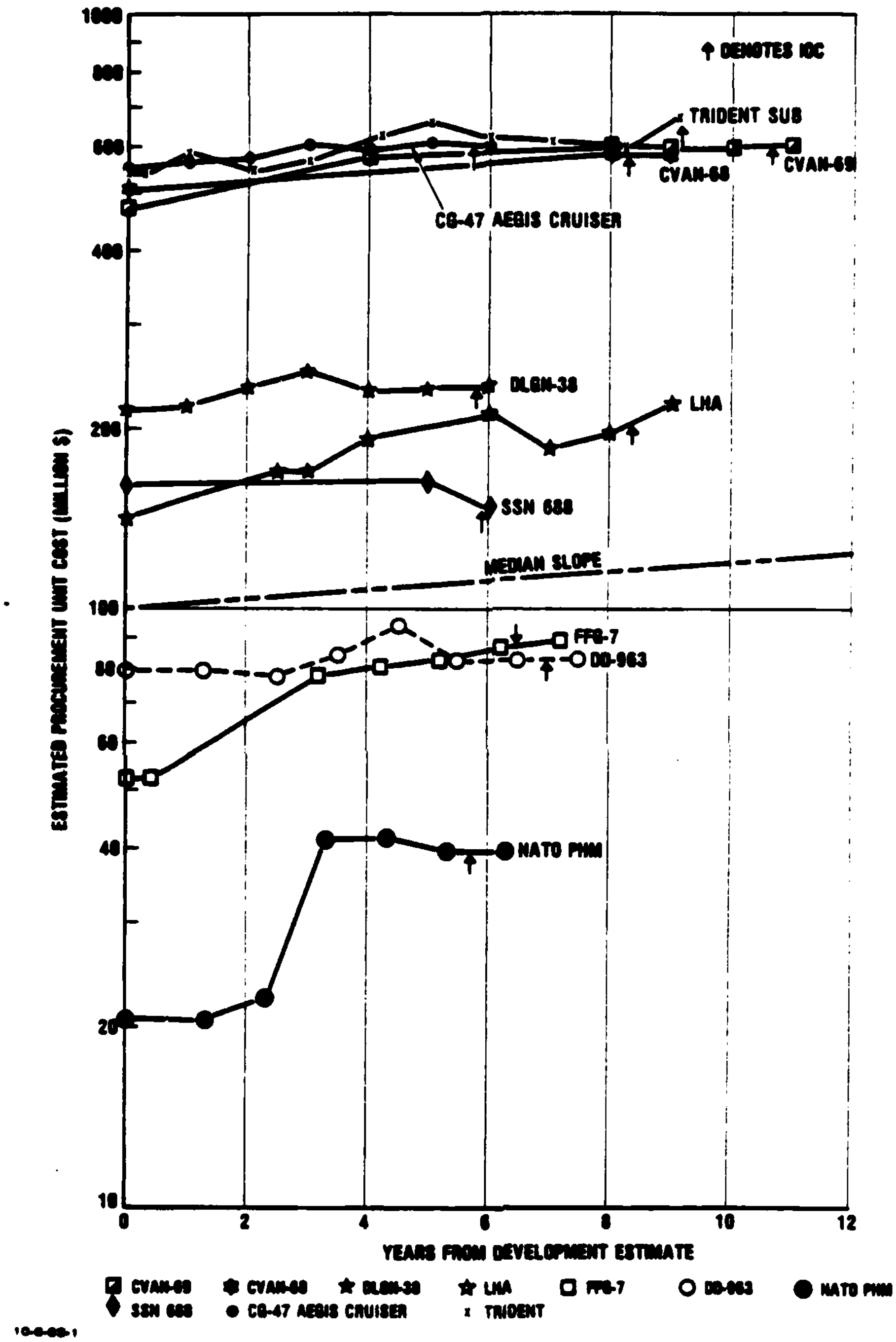

Figure 16. PROCUREMENT UNIT COST GROWTH, SHIPS

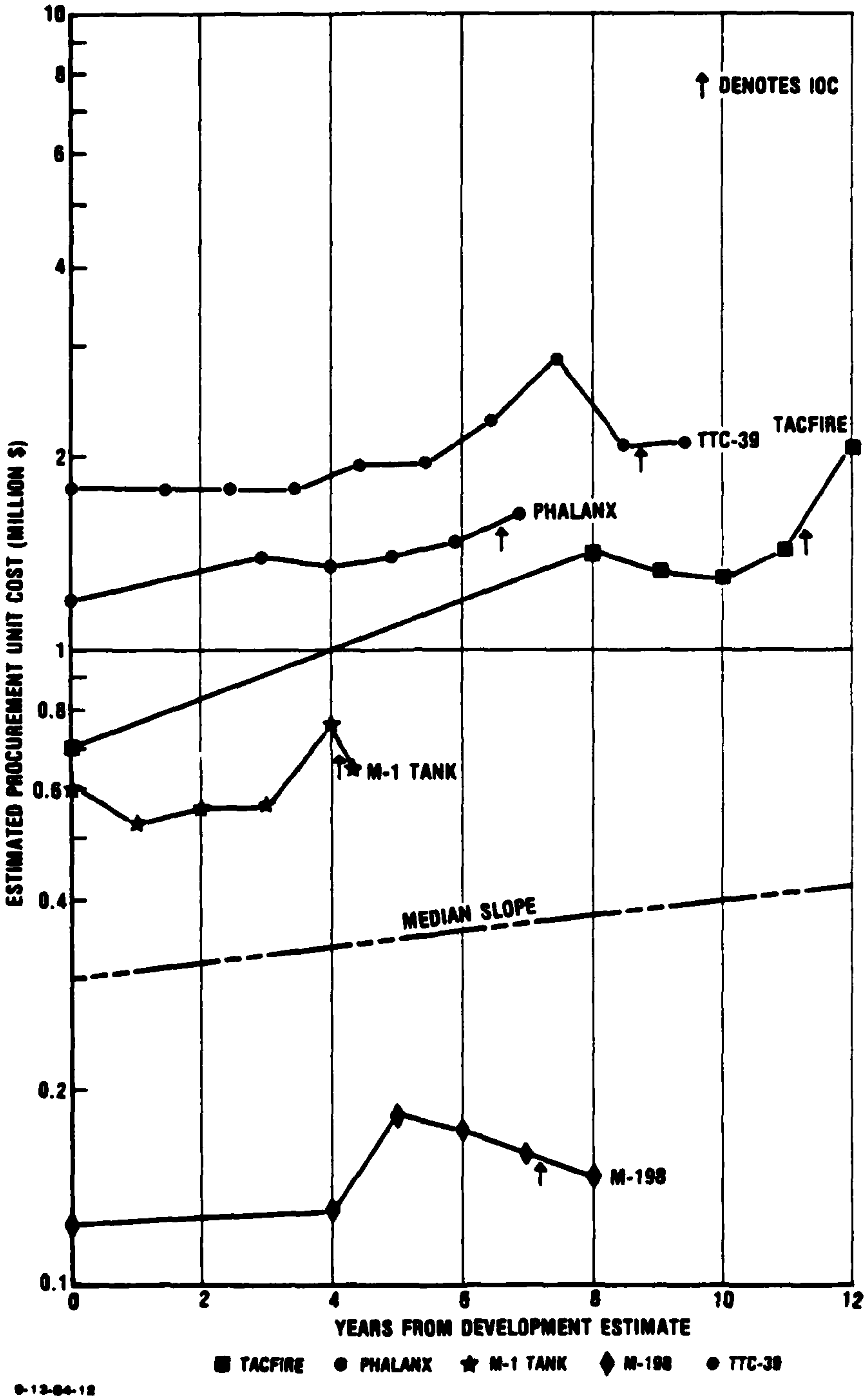

Figure 17. PROCUREMENT UNIT COST GROWTH, OTHER

V. A METHODOLOGY FOR PROJECTING SCHEDULE AND COST GROWTH

A. INTRODUCTION

An analyst's capability to project probable growth in weapon systems baseline estimates is a function of the current stage of system development and information available (e.g., Baseline Cost Estimate, Independent Cost Assessment, Decision Coordinating Paper, Integrated Program Summary, SAR, etc.). As a system matures, information and data become more specific and trends more visible; hence more refined growth projection techniques can be used over time, and hopefully result in more accurate schedule and cost estimates. Use of a specific technique by an analyst must be tempered by a subjective evaluation of all available information. To facilitate understanding the methodology, let us expand upon the information contained in Chapter III of this report, and assume that Fig. 18 represents the typical acquisition cycle time line applicable to any weapon system development program. For convenience, we have partitioned the time line into specific time segments. The breakpoint between segments was nominally established as the date of the Milestone decision meeting. In actuality, the time segment will begin several months prior to one Milestone and end several months prior to the next Milestone. This offset occurs because of the time required to develop, refine, coordinate, staff and obtain Service and OSD approval of the schedule and cost estimates used at the DSARC decision meetings.

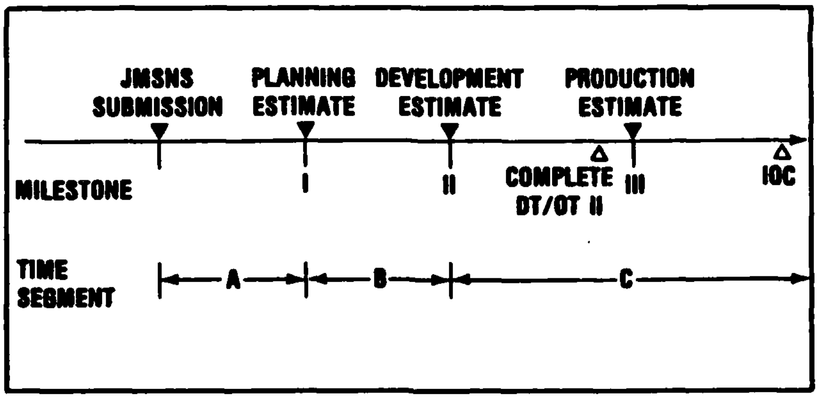

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Figure 18. ACQUISITION CYCLE TIME LINE

TIME SEGMENT A

During this period, a Justification for Major System New Start (JMSNS) is approved by OSD. As part of the approval process, the DoD Component(s) identifies the general magnitude of acquisition resources they would be willing to invest to correct the deficiency. No engineering cost estimate is prepared at this stage because a candidate system has not been defined. Lacking adequate system definition, the schedule and cost growth methodology proposed in this paper is not applicable to any program whose current stage of development lies with Time Segment A.

TIME SEGMENT B

This period extends from the initial preparation of the Planning Estimate (PE), which is presented to DSARC principals at decision Milestone I, to the point in time when the preparation of the Development Estimate (DE) is initiated. Unfortunately, schedule and cost data on systems which have progressed through Time Segment B and have attained IOC are quite limited. It should be noted that at

present, there are no pre-Milestone II systems being reported upon via the SAR. Usually, the PE is a rough estimate based, in part, on parametric costing techniques. An earlier OSD study[1] provided *current dollar* cost data on 36 programs which were in production (i.e., had passed Milestone III but not IOC). Although its objective was to document the reasons for cost growth, the OSD study did, in fact, report that the estimated program acquisition costs (development, procurement and MILCON) for the 36 systems grew by a factor of 2.3 during the period between Milestone I and Milestone III. A caveat: no suggestion was made or inferred in the OSD study to the effect that the factor (2.3) could or should be used to project future costs of analogous developmental programs. Using data contained in post-1975 SAR submissions and appropriate OSD inflation indices, we converted the current dollar Planning Estimate costs for 16 of the 36 systems to a constant dollar base. That data, together with data on 6 additional systems, are presented in Table 5 simply to demonstrate that program growth does occur between Milestone I and Milestone II.

For systems in Time Segment B, the IDA projection methodology assumes that only the Planning Estimate schedule and cost data are available (i.e., no subsequent SARs are available). In those circumstances where updated data are available, follow the procedures for Time Segment C. In applying the Segment B methodology, one must first calculate the probable schedule growth:

[1]Memorandum for Distribution, "System Acquisition Cost Growth Study," Office of the Director of Defense Program Analysis and Evaluation, November 12, 1973.

Table 5. PROGRAM ACQUISITION COST GROWTH, PE TO DE

Category	System	Base Year	Estimated Program Acquisition Costs (Millions of Base Year Constant Dollars) At Planning Est. Approval Date	At Development Est. Approval Date	Cumulative Total Growth Factor PE to DE
Aircraft	A-10[1]	1970	1,768	1,768	1.00
	E-2C	1968	411	531	1.29
	F-14[1]	1969	5,391	5,391	1.00
	F-15	1970	4,675	5,988	1.28
	P-3C	1968	814	1,294	1.59
	UH-60[1]	1971	1,942	1,942	1.00
	MEDIAN				1.14
	MEAN				1.19
Missiles	DRAGON[2]	1966	383	404	1.05
	HARPOON	1970	804	795	0.99
	I-HAWK	1969	336	588	1.75
	MK-48	1972	609	1,672	2.75
	MAVERICK (A/B)	1968	224	332	1.48
	MINUTEMAN III[2]	1967	2,695	4,674	1.73
	PHOENIX[2]	1963	371	536	1.44
	SIDEWINDER[1]	1971	87	87	1.00
	SPARROW	1968	140	454	3.24
	TOW	1966	410	727	1.77
	MEDIAN				1.61
	MEAN				1.72
Ships	CVAN 68 / CVAN 69	1967	863	981	1.14
	DD 963	1970	1,504	2,395	1.59
	DLGN 38	1970	675	722	1.07
	LHA	1969	580	1,291	2.23
	MEDIAN				1.37
	MEAN				1.51
Other	M-1 TANK	1972	3,005	4,779	1.59
	MEDIAN/MEAN				1.59
Composite	MEDIAN				1.44
	MEAN				1.52

[1]PE = DE (Per notation in SAR).

[2]SAR indicates no escalation in original estimates, PE and DE.

Step 1. Using the program milestone schedule approved at DSARC I, determine the estimated time (in years) from DSARC I to IOC.

Step 2. Select the appropriate weapon system category median cumulative total schedule growth factor from Table 2 (e.g., aircraft = 1.09).

Step 3. Multiply the time span (in years) by the schedule growth factor, then increase the product by 20 percent.[1]

Step 4. Convert the resultant time span to years and months; add this figure to the date of the planning estimate to obtain the probable date of IOC attainment.

Once the adjusted time span between the PE approval date and the revised IOC date has been determined, a projection of the development cost and procurement unit cost (at IOC) can quickly be calculated using the following formula:

$$C_{IOC_{(x \text{ or } y)}} = (CGF)^{s}_{(x \text{ or } y)} \times C_{PE_{(x \text{ or } y)}}$$

where

C_{IOC} = Probable cost at projected IOC date
x = Development cost
y = Procurement unit cost
CGF = Median cumulative average growth factor from Tables 3 or 4, as appropriate
s = Time span in years, PE to projected IOC date
C_{PE} = Estimated cost at date of planning estimate approval (Milestone I).

[1]This factor was developed based on a limited sample of seven systems for which we were able to obtain PE, DE, and actual IOC data.

To illustrate how the methodology is applied, assume that a new aircraft program is being evaluated and the following schedule and cost data have been extracted from the DCP and IPS.

Schedule

Milestone I	- June 1980
Milestone II	- June 1982
Milestone III	- December 1985
IOC	- June 1987

Estimated Costs
(FY 81 Constant $ in millions)

Development	- $2,250
Procurement unit	- $12.5

Projected IOC

1. Time span Milestone I to IOC - June 1987-June 1980 = 7 years.
2. Median cumulative total schedule growth factor, aircraft = 1.09.
3. Adjusted time span = 7 x 1.09 x 1.2 = 9.15 = 9 years, 2 months.
4. Projected IOC = June 1980 plus 9 years and 2 months = August 1989.

Projected Development Cost at IOC

$C_{IOC_x} = (1.058)^{9.2} \times \$2,250 = \$3,780$ million.

Projected Procurement Unit Cost at IOC

$C_{IOC_y} = (1.038)^{9.2} \times \$12.5 = \$17.6$ million.

TIME SEGMENT C

This segment begins with the initial Service "approval" of the Development Estimate prior to the DSARC II meeting and extends through the IOC date. The key event during this segment (with respect to our proposed schedule and cost projection methodology) is the successful completion of development testing and operational testing, referred to as DT/OT II, TECHEVAL/OPEVAL, or DTE depending upon the Service involved. It is almost axiomatic that the degree of success achieved in a testing program will determine how much additional schedule and cost growth a program will experience prior to IOC. As might be expected, our historical data indicate that there is a high probability of schedule slippage associated with completion of DT/OT II.

In Time Segment C, when only the Development Estimate schedule and cost data are available (i.e., no subsequent SARs are available), we recommend the following procedure for predicting probable schedule and cost growth. In this circumstance, one would first select the appropriate category median cumulative total schedule growth factor from Table 2 and then multiply the estimated time interval from the DE approval date to the expected IOC date (in years) times the schedule growth factor. Convert the resultant to years and months and add it to the date of DE approval, thus yielding the probable IOC date. In similar fashion, select the appropriate development cost and procurement unit cost median cumulative average growth factors from Tables 3 and 4, then multiply the cost values contained in the DE by the cumulative average growth factors compounded over the time span in years from the DE approval to the adjusted IOC date to obtain the probable cost

values at IOC. This procedure should only be used when current data are not available; it should *not* be used once the first updated December SAR is available. In the latter circumstance, the procedures discussed in the following sections should be used.

B. SCHEDULE GROWTH PROJECTION METHODOLOGY

As noted in Section IV.E., we were not able to identify any systematic trend toward either convexity or concavity in schedule growth plots. Accordingly, we recommend that the following formula be used to compute the time span from the current SAR date to the IOC date:

$$P_{IOC} = SGF \times CE_{IOC}$$

where

P_{IOC} = Projected time span (in years) from current SAR date to IOC date

SGF = Median cumulative total schedule growth factor (Table 2)

CE_{IOC} = Time span (in years) from current SAR date to current estimate of IOC date.

The above formula assumes the program under consideration will experience a "median" amount of schedule slippage from the current SAR date to IOC. If the analyst has information that indicates that the program will probably experience either more or less than normal schedule slippage, then he should adjust the value of SGF accordingly.

C. COST GROWTH PROJECTION METHODOLOGY

The probable acquisition cost of a weapon system at IOC can be projected from current SAR data using the following equation:

$$C_{IOC_{(x \text{ or } y)}} = (CGF)^{P_{IOC}}_{(x \text{ or } y)} \times C_{CE_{(x \text{ or } y)}}$$

where

C_{IOC} = Probable cost at projected IOC date

x = Development cost

y = Procurement unit cost

CGF = Median cumulative average cost growth factor from Table 3 or 4, as appropriate

P_{IOC} = Projected time span (in years) from current SAR date to IOC date (from Section V.B. above).

C_{CE} = Current estimate of cost

As noted in the schedule growth projection methodology, the above equation assumes the program under consideration will experience a "median" amount of cost growth from the current SAR estimate to IOC. If the analyst has information that indicates that the program will probably experience either more or less than normal cost growth, then he should adjust the value of CGF accordingly.

D. SUMMARY

Cost growth in major (and non-major) weapon system acquisition programs continues to be of vital concern to the Congress and key decision makers within the Department of Defense. The capability of projecting probable future growth in a specific program is a necessary tool for effective acquisition management. This paper describes the development of a relatively simple methodology for projecting schedule and cost growth in a weapon system program. The schedule and cost growth projection methodology outlined in this paper is recommended for use in IDA evaluations of weapon system development programs. It could also be of value to other agencies/elements of the DoD cost analysis community.

CITED REFERENCES

1. *A Range of Cost Measuring Risk and Uncertainty in Major Programs--An Aid to Decisionmaking.* Report to the Congress by the Comptroller General of the United States, February 2, 1978.

2. Analytic Services, Inc., *A Survey of Techniques for Improving Cost Estimates of Future Weapon Systems,* ANSER Memorandum AM-65-2, R. D. Carter, March 1965.

3. The Rand Corporation, *Choice Among Strategies for System Acquisition,* Rand Corporation, P-4794, A. J. Harman, March 1972.

4. The Rand Corporation, *Cost Estimates as Predictors of Actual Weapons Costs: A Study of Major Hardware Articles,* Rand Memorandum RM-3061-PR (Abridged), Robert Summers, March 1965.

5. Nelson, B.B., *Improving Cost Estimating and Analysis In DOD and NASA,* The George Washington University, D.P.A., 1972.

6. Howard, Truman W. III, *Methodology for Developing Total Risk Assessing Cost Estimates (TRACE),* U. S. Army Missile Research and Development Command, Redstone Arsenal, Alabama, 1978.

7. *Financial Status of Major Federal Acquisitions,* Report to the Congress by The Comptroller General of the United States, September 30, 1978.

8. *Inaccuracy of Department of Defense Weapons Acquisition Cost Estimates,* Ninth Report by the Committee on Government Operations, November 16, 1979.

9. Parkinson, C. Northcote, *Parkinson's Law and Other Studies in Administration,* Houghton Mifflin Company, Boston, 1957.

10. Allen, Wayne M., *Should Cost/Will Cost/Must Cost--A Theory on the Cause of Cost Growth.* U. S. Army Safeguard System Office, Arlington, Virginia, June 1972.

11. The Rand Corporation, *Bias in Initial Cost Estimates: How Low Estimates Can Increase the Cost of Acquiring Weapon Systems*. Rand Report R-1467-PA&E, Joseph P. Large, July 1974.

UNCITED REFERENCES

A Cost Performance Forecasting Concept and Model, Cost Research Report No. 117, Cost Analysis Division, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, November 1974.

A Production Study Sequel to the Cost Performance Forecasting Concept and Model, Cost Research Report No. 132, Directorate of Cost Analysis, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, August 1976.

Automated Financial Analysis Program, A User's Guide, Cost Analysis Division, Electronic Systems Division, Hanscom AFB, Bedford, MA, November 1976.

Babiarz, A.S. and P.W. Giedras, *A Model to Predict Final Cost Growth in a Weapon System Development Program,* Air Force Institute of Technology, August 1975.

Buckelew, W.F., *Economic Escalation and the Military Program Manager,* Defense Systems Management School, Ft. Belvoir, VA, November 1975.

Computer Program Input Instructions for Cost Performance Forecasting Model, Cost Research Report No. 117-A, Cost Analysis Division, Aeronautical Systems Division, Wright Patterson AFB, Ohio, February 1975.

Cost Growth in Major Weapon Systems, Comptroller General of the United States, March 26, 1973.

Cost Performance Forecasting Study, Cost Analysis Division, Space and Missile Systems Organization, Los Angeles, CA, June 1977.

Cummins, J.M., *Cost Overruns in Defense Procurement: A Problem of Entrepreneurial Choice Under Uncertainty,* Dissertation, Northwestern University, 1973.

Dienemann, Paul F., Memorandum, *Study of Weapon System Cost Growth,* OSD, Office of the Director, Planning and Evaluation, Washington, D. C., August 9, 1976.

Glover, W.L. and J.C. Lenz, *A Cost Growth Model for Weapon System Development Programs*, Air Force Institute of Technology, 14 August 1974.

Henry, D.D., *Statistical Analysis of the Effectiveness of Program Initial Conditions as Predictors of Weapon System Acquisition Program Success*, Naval Postgraduate School, Monterey, California, December 1976.

Launer, R.L., H.F. Candy, and S.H. Carter, *Cost Growth Effects of Contract Size, Duration, Inflation, and Technology*, Procurement Research Office, USALMC, Ft. Lee, VA, May 1972.

Lewis, Edwin M. and Eugene D. Pearson, *The Air Force Cost Estimating Process: The Agencies Involved and Estimating Techniques Used*, Air Force Institute of Technology, June 1977.

Management Consulting and Research, Inc., *Cost Growth in Navy Selected Acquisition Reports (SARS)*, TR-7817-1, Clifton N. Horton, et al., 25 July 1979.

Martin, M.D., *A Conceptual Cost Model for Uncertainty Parameters Affecting Negotiated, Sole-Source Development Contracts*, Dissertation, The University of Oklahoma Graduate College, 1971.

The Rand Corporation, *System Acquisition Strategies*, Rand Corp., R-733-PR/ARPA, R. Perry et al., June 1971.

The Rand Corporation, *An Overview of Acquisition Policy Effectiveness in the 1970s*, Rand/WN-10435-DR&E, G.K. Smith, February 1979.

Schow II, H., *Macrobehavior of Development Costs and Estimates (STEC Plots)*, Systems and Cost Analysis Division, U. S. Army Materiel Command, Washington, D.C., Technical Report 68-2, September 1968.

The Army Cost Estimating and Monitorship Subcommittee, *Report to The Army Acquisition Management Task Force*, Department of the Army, Office of the Assistant Secretary, 28 November 1979.

Trainor, Richard James, *Study of Factors Leading to Changes in Cost Estimates on Selected Major Department of Defense and National Aeronautics and Space Administration Development Systems*, Ph.D. Dissertation, The George Washington University, 1977.

Webb, Donald E., *The Study of Cost Growth of a Major Weapon System*, Naval Postgraduate School, Monterey, California, December 1974.

Weida, Major William J., *A General Technique for R&D Cost Forecasting*, USAF Academy, Colorado, September 1977.

Weida, Lt. Col. William J., *Forecasting Expenditures for Weapons*, U.S. Air Force Academy, Colorado, July 1979.

Weida, Lt. Col. William J., 2Lt. Steven D. Clark, and 2Lt. James E. Rowland, *Determining Government Disbursements from Normalized Spending Patterns*, USAFA-TR-79-4, U.S. Air Force Academy, Colorado, May 1979.

REFERENCES FROM ALVIN J. HARMAN PAPER

[1] Klein, B.H., "The Decision-Making Problem in Development," in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, 1962.

[2] Peck, M.J. and F.M. Scherer, *The Weapons Acquisition Process: An Economic Analysis*, Graduate School of Business Administration, Harvard University, 1962.

[3] Marschak, T.A., T.K. Glennan, Jr., and R. Summers, *Strategy for R&D: Studies in the Microeconomics of Development*, Springer-Verlag, New York, 1967.

[4] Perry, R., G.K. Smith, A.J. Harman, and S. Henrichsen, *System Acquisition Strategies*, R-733-PR/ARPA, The Rand Corporation, June 1971.

[5] Harman, A.J. (assisted by S. Henrichsen), *A Methodology for Cost Factor Comparison and Prediction*, RM-6269-ARPA, The Rand Corporation, August 1970.

REFERENCES FROM TRUMAN W. HOWARD PAPER

[3] Comptroller General of the United States. *Cost Growth in Major Weapon Systems*. Report to the Committee on Armed Services, House of Representatives. Washington, D.C.: Government Printing Office, 1973.

[10] Peck, M.J. and Scherer, F.M. *The Weapons Acquisition Process: An Economic Analysis*. Boston: Harvard University, 1962.

[12] Trainor, R.J. *Study of Factors Leading to Changes in Cost Estimates on Selected Major DOD and NASA Development Systems*. Doctoral Dissertation, George Washington University, Washington, D.C., May 1977.